Building Technological Innovation Capabilities in Chinese firms: Opportunities and Challenges

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Abstract

How are the Chinese firms making the transition from imitation to innovation which is considered as the source of their sustained long-term growth? Focused on the telecom-equipment sector, this study examines the growth of Chinese firm's technological innovation capabilities. Based on the previous research on Technological learning, Technological Catch-up, theories regarding to Technological Innovation Capabilities, some research propositions are developed. Case study approach is used as the beginning of the research work. Through the case studies of Shanghai Bell, Huawei, ZTE, Datang and Great Dragon, this study analyzes how catching-up in the telecommunication industry was realized. Some important factors which contribute to the building up of the TICs in the Chinese firms are also be identified, such as technology platform, financial support from government, intensive internal learning system and variety of international and research linkages.

Keywords: Technological Innovation Capabilities, Technological learning, catching-up, knowledge diffusion, telecom-equipment, technology latecomer, China.

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1. Introduction

During the last 20 years, China has maintained a high rate of economic growth that has attracted worldwide attention. China's rise as the "workshop of the world", that is now often called another East Asian Miracles, has been attributed to China's success reform to take advantage of comparative advantage in labor-intensive goods (Lin, Cai, & Li, 2003). Economic reforms in China have benefited significantly from the increasing effects of innovative learning; that is, learning is in a competitive environment at both macro and micro level (Zhang & Taylor, 2001). China's technological path reflects in many respects the experiences of Japan and South Korea in their rapid growth periods; although differences between China and her neighbors have also been pointed out (Lee et al., 2002). In the context of globalization and transition to a knowledge economy, innovation and technological change have become increasingly important to China's economic growth and the competitiveness of Chinese firms.

Over the past three decades, many studies have looked at the processes of successful technological learning in the industrialization of developing countries. It is believed that, in general, newly industrialized countries initially learn technologies from developed countries, and then build their own technological capabilities step by step. In fact, the story of technological learning is also related to the catch-up theory originally proposed by Gershenkron (1962) and Perez and Soete (1988), and later studied in Hobday (1995), Kim (1997), Lee and Lim (2001), Kim and al. (2004) and Lee and al. (2005).

Gershenkron (1962) studied the catch-up by 19th century German and later Russian companies in the steel industry and argued that the latecomer firms could acquire and use the latest technology, at much lower costs than those in the pioneering countries, by transfer agreements, inward investment and the recruitment of skilled people. Perez and Soete (1988) in their study endorsed Gerschekron's theory of latecomer advantages, and provided a more general theory of the science and technology infrastructure needed for effective catch-up. Hobday (1995) indicates that numerous ways can be used by developing countries to obtain foreign new technologies, such as purchase of equipment, licensing, sub-contracting, foreign direct investment (FDI), hiring foreigners, hiring returning nationals, joint ventures/strategic alliances, original equipment manufacture (OEM), acquisition of overseas firms, research and development (R&D). East Asian countries, especially South Korea and Taiwan, all designed in these different ways steadily to upgrade their local technological capability. Kim (1997) defines technological learning as "the acquisition and assimilation of existing knowledge and, more important, the creation of new knowledge" (p.103). Based on the study of different industries in South Korea, he identified three sub-categories of sources of learning, which are the international community, domestic community and in-house efforts at firm level. However, lots of researchers noted that it is not easy for a developing country to proceed from the stage of imitation to the stage of innovation. Bell and Pavitt (1993) indicated that just installing large plants with foreign technology and foreign assistance will not help in the building of technological capability. In the case of Korea, Lee and Lim (2001) attempt to answer the question of what the conditions were for technological catch-up and leapfrogging. They argue that regimes in which innovation is more predictable and frequent, will give latecomers more opportunity to catch up, such as Dynamic Random Access Memory (DRAM) and automobile industries in Korea. Based on detailed case studies in three strategic divisions of the Korean company, Kim and al. (2004) categories the transition process from imitation to innovation into four stages – external learning, internal learning and generation, dependent external performance and independent external performance. Lim et al. (2005) in their study discuss the leapfrogging with the case of catch-up in digital TV by the Korean firms. They illustrated that the Korean firms had achieved a "path-creating catch-up" in the sense that they chose a different path from the forerunning Japanese firms.

Nevertheless, imitation is usually easier and less costly than innovation. A very big gap in technology does provide a potential for fast catch-up (Freeman, 2002). As many researchers noted, mastering existing technologies is more significant than innovation as the focus of technological activity, especially for most of developing countries. Learning therefore has an important role to play in technological innovation. But with industrial maturity, there will be an inevitable shift in technological effort from these to more demanding innovation, calling for higher levels of skill and more R&D effort.

Our paper discusses the development of high-tech industry and the dynamics of technological learning, innovation and entrepreneurship in China through the telecom-equipment industry. More specifically, we try to answer the following questions: Whether the Chinese firms could graduate from imitators to creators, as firms and industries in other late-learner nations like Japan and Korea were able to do earlier? Where does the needed knowledge come from? Is innovation capability necessary for latecomer like China? Should the indigenous firms in late-industrialized countries wait until they are at the late-stages of their catching-up to develop their innovation capability? What's the role of government in helping to construct competitive indigenous firms that could take on global giants?

In what follows, we will provide a brief overview on the evolution of China's technological learning from 1949 to 2006 in Section 2, and then discuss the propositions and the methodology of our study in Section 3. Section 4 presents a detailed analysis of catching-up in China's telecom-equipment industry using four examples. Section 5 discusses the results of our study. Last section states the conclusion, limitation and further research.

2. Evolutionary stages of China's technological learning

The "Open Door" policy of Deng Xiaoping in 1979, gave an impetus to rapid transformation and an astonishing dynamic of technological learning in the Chinese so-called "socialist-market economy". With a surprising pace, China is absorbing FDI, creating a large middle class, learning to adapt Western technologies, even in some sectors move to the stage of original innovation. By end of 2006, China spent over US$230 billion on R&D, for the first time surpass Japan and so becomes the world's investor in R&D just after the United States, according to OECO (Organization for Economic Cooperation and Development, 2006). On the cover of *BusinessWeek* magazine, a provocative headline in October 2002:

High Tech in China: is it a Threat to Silicon Valley?

While a deliberately provocative headline, the question is one that researchers and practical experts are beginning to ask more and more.

In fact, since the Chinese Communists took control of the country in 1949, the Chinese leadership has attempted to modernize China's Science and Technology (S&T) system through a set of policymaking. These policies drive a dynamic of technological learning in China's modernization process. According to Xie and White (2006), the technological learning process of China can be divided into four historical periods: 1949-1960, 1960-1978, 1979-1991, 1992-2000, and a rising fifth period: 2001-onward (see fig. 1). A common characteristic in all of these four stages is that China attempts to catch up to the West. However, the first four periods are grouped as imitation paradigm, while the fifth period – characterized by global competitiveness, knowledge management and Chinese firms themselves as a significant source of learning – is considered as creation paradigm (Xie & White, 2006, p.230). Indeed, China was very successfully by all measures in the phase of imitation paradigm.

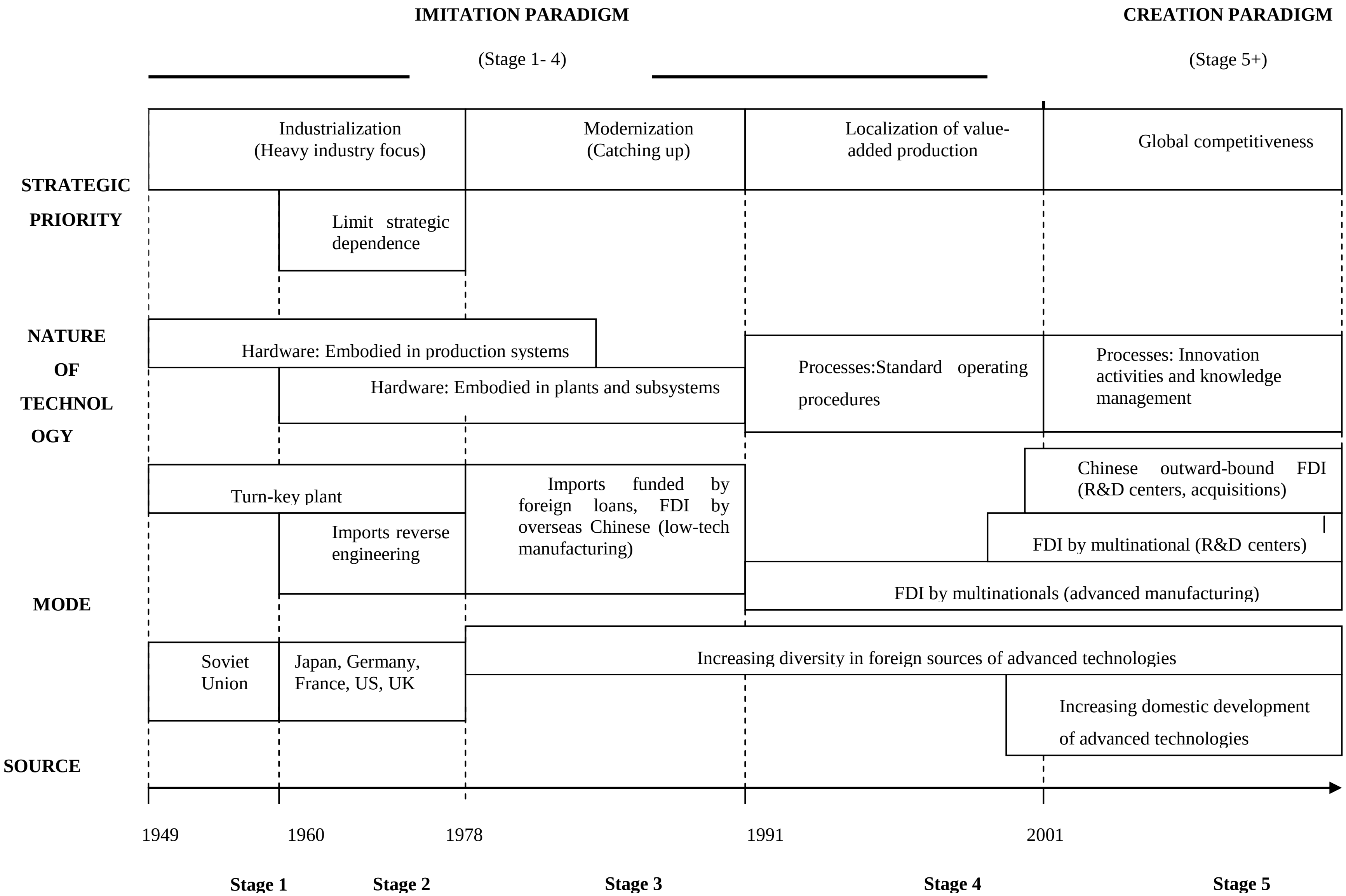

Figure 1: Stages in China's technological learning

Source: Xie & White (2006)

While the timing and rate of transition to the fifth period – creation paradigm varies significantly by industries and firms, entrance of World Trade Organization (WTO) for China in 2001 is an important demarcation at the national level. WTO entry indicates that the Chinese government began to have a clear policy of fostering local firms to become global competitors in both domestic markets and global markets. Meanwhile, the nature of technology has also changed in this new paradigm. Compared with prior strategic priorities met by drawing on a pool of technology developed by others, the creation paradigm requires firms to develop the capabilities to create their own technologies (Xie & White, 2006, p.235).

3. Propositions and research methodology

Among the numerous studies on technological catch-up, some researchers take a technological regime approach. The technological regime consists of technology opportunity, appropriability of innovations and cumulativeness of technical advance and the property of knowledge base (Breschi, Malerba, & Orsenigo, 2000). For instance, Lee and Lim (2001) have built a model of technological and market catching-up to explain the evolution of selected industries in Korea. They pointed out that the technological regime plays an important role in explaining why some industries such as DRAM and automobile in Korea have caught up and others not, such as PC and house electrical appliance. They concluded that the key for success or failure of catching-up in the industry is whether the innovation is predictable or not.

Despite the significant research progress in the field of technological learning relevant to developing countries, there is very little literature concerning China. Meanwhile, some researchers have already started filling this gap. For instance, Xie (2004) suggests that learning process occurring in China’s CTV is inherently the same as that of other NIEs (Newly Industrializing Economies). However, there are some differences in technological learning between China and other NIEs. China is a big country with a huge domestic market. Firms in China’s CTV industry can combine marketing skills for the domestic market with imported assembly lines to enter the market and build a brand name in the domestic market. Therefore, it seems that there is a greater opportunity for Chinese firms, compared with latecomer firms from other smaller NIEs, to utilize its cheap labor cost and economies of scale in an international market. Chen and Qu (2003) developed a framework for the new technological learning in China and illustrate it by using a case. Based on a modified version of Lee and Lim’s model of technological learning and catching-up, Mu and Lee (2005) examined the growth of technological capability in the telecommunication industry in China. They found 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, their study also pointed out that the technological regime of the telephone switches is featured by a more predictable technological trajectory and a lower cumulativeness.

We agreed with Mu and Lee (2005) that the diffusion of new technology and the accumulation of knowledge is very important in China's catching-up process, but go beyond these elements, we have to ask how domestic firms entre the industry to compete with foreign companies; how can Chinese firms learn and build their innovation capability; why some firms succeed, and others not. In the telecom-equipment industry, local manufacturers, such as Huawei, Datang, ZTE entered into the global system for mobile communication (GSM) area much later than MNCs. However, Huawei, for example, has used its local advantage and innovation capability to achieve unforeseen success in the value-added part of GSM and upgraded itself to keep pace with the global development of the third generation wireless communications system (3G) in later stages. Thus based on the previous studies in the field of technological learning in China, we suggest the following propositions:

Proposition 1. The innovation capability and self-developed technologies are the keys to domestic firms' catching up with the MNCs.

Proposition 2. The domestic firms in late-industrialized countries should develop their innovation capability even during the earlier stages of catching-up process.

Proposition 3. In-house R&D development supplemented with external alliance is a major means for leading domestic firms to build their innovation capability.

Previous studies on technological learning in developing countries were based both on statistical survey, mathematical modeling and case studies. Questionnaires and models are constrained by rigid limits, and hard to analyze the software in management of technology, e.g. human behavior (Clark & Fujimoto, 1991). Case research enriches not only theory, but also the researchers themselves (Ren, Krabbendam, & Weerd-Nederhof, 2006). We believe a case study approach is very important as beginning of this research work. However, to keep the case study consistent and the data reliable, we conduct our study not only through anecdotal information, companies' reports, and overall conclusions by experts in the field, but also with intensive interviews with open-ended questions.

Why telecom-equipment industry?

With an expansion rate of 30-50 percent annually, China's telecommunications sector has been growing faster than the economy as a whole since 1989. In 2003, China became the largest telecommunications market in the world due to the combined total of 532 million fixed and mobile telephone subscribers, a point reinforced by the International Telecommunication Union (ITU) recognition of China as a "telecommunications superpower". However, the penetration rates of fixed and mobile telephones in China still remain low at 21.2 percent and 20.9 percent respectively in 2003 (Low, 2005). Moreover, the telecom-equipment is one of the most R&D intensive-industries, with leading MNCs spending on average between 10 to 20 percent of their revenues in R&D in 2006. Its high dependence on R&D concludes that our choice will be relevant to verify classical arguments about the experiences of catch-up of latecomers in NICs.

4. Catching-up in China's telecom-equipment industry

Reviewing the development history of China's telecom-equipment industry, some domestic manufacturers have achieved significant success in catching-up the multinationals. We can divide the catching-up process into three stages, that is, phone digital switches, GSM and 3G. In order to demonstrate how domestic firms narrow their technological gap in these different stages and how these firms have been influenced by their innovation capabilities to catch up to the multinationals, four examples will be made use of..

4.1. Overview of major domestic telecom-equipment manufacturers in China

A large part of Chinese telecom-equipment industry's history and identity is attributable to the development of local manufacturers. Preference for domestic firms, through a vast network of relationships and *"guanxi"* that are typical in China (Ambler, 1995; Farh et al., 1998), resulted in foreign manufacturers being disadvantaged when bidding for major national contracts.

Huawei Technology Corporation (Huawei), the largest telecom-equipment providers in China, was instituted in 1998 by Ren Zhengfei. It is also the leader in providing next generation telecommunications network solutions for operators around the world, and counts the four largest Chinese operators (China Telecom, China Mobile, China Unicom and China Netcom) as its customers. Till now, the giant employs 44,000 workers worldwide, mainly based in Shenzhen, but also in Europe, India, North America, and in other parts of China. Huawei's contract sales reached US$11 billion in 2006, up 34 percent from 2005. Domestic sales in 2006 were US$3.85 billion, 65 percent of the contract sales came from the international market (US$7.15 billion) which has become the major driver of sales growth. Up till 2006, 31 of the world's top 50 telecom operators including Vodafone, BT, Telefonica, FT/Orange and China Mobile have selected Huawei as their corporate partner. (Huawei's Annual Report, 2006).

Shenzhen Zhongxin Technology Corporation (ZTE) was established in 1985. It was the result of the Chinese government initiative to promote indigenous technological abilities in telecom-equipment industry. In 1997, ZTE was listed in the Shenzhen Stock Exchange, and till now it continues to be the largest publicly-listed telecom-equipment firm in China. ZTE only started to target the international market in the last year, after it saw how well Huawei has done.

Shanghai Bell commenced as a joint venture between Shanghai Telecom Administration, Alcatel and the Belgian Government. The company became majority owned by Alcatel (50 percent plus one share) in 2002 and changed its name to Alcatel Shanghai Bell. The merger with Alcatel brought with it benefits of research and development (R&D) and the expansion of new product lines beyond its traditional focus on central offices, which had been under severe competition from Huawei and ZTE.

Datang Telecom Technology Co., Ltd and **Great Dragon Information Technology** have similar major product ranges with Huawei and ZTE, but the two former firms have much less R&D and production facilities than Huawei and ZTE (see Table 1).

Table 1: Overview of major domestic telecom-equipment manufacturers in China

	Huawei	**ZTE**	**Datang**	**Great Dragon**
First office	1988	1985	1998	1994
Number of employees	18,000	12,916	4183	2500
Total sales revenue -2002(US$)	2.7 billion	1.3 billion	0.247 billion	0.240
R&D expenditure (US$)	0.36 billion	0.21 billion	0.03 billion	0.026 billion
% of total sales revenue	13.3%	15%	12.3%	11 %

Source: ChinaNex.com; company information

4.2. The role of Shanghai Bell in the development of digital switches

In the earlier stage, both domestic firms and university and public research institutes in China lacked relevant knowledge of digital switches. Knowledge diffusion from the foreign Joint Ventures (JVs) was critical for later on emerging of domestic firms (Mu & Lee, 2005). The JVs, such as 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. As most of Chinese counterparts in the JVs were state-owned enterprises (SOEs) at that time, more often, regional telecommunication equipment companies of Ministry of Post and Telecommunication (MPT). So MPT sometimes would use the advantage of that to ask Shanghai Bell to have R&D consortium with domestic firms. For instance, 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 and later on conducted the success of indigenous switch, HJD-04.

The key engineer of the HJD-04, Mr.Wu had years of experience with Japan F-150 system, before that, he was an engineer for computer research. The research team of the HJD-04 started with conducting research on Shanghai Bell’s System-12, using publicly available documents. 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 Luoyang Telephone Equipment Factory (LTEF), the main manufacturer of the HJD-04 even sought direct technical help from the Shanghai Bell. As a result, the new product integrated the advantage of Fujitsu’s F-150 (Centralized control system), Shanghai Bell’s S1240 (distributed control system) and computer design (Gao, 2004). Encouraged by government as well as its cost advantage, HJD-04 became a game winner in the market. To summarize, without the diffusion of the technology related to digital automatic switches embodies in the System-12 and other projects in the Shanghai Bell, the indigenous technological development of

HJD-04 might not have been possible.

Great Dragon was the first company to sell the HJD-04. It was established as a company of LTEF in 1995. The emergence of Great Dragon became the symbol of national hero to break the dominance of foreign companies. But in digital switches market, coming late means got more. Huawei and ZTE, both of them with an ownership structure of private companies aimed the low-end market with their own technology (Liu, 2007). As the same time, Great Dagon as a SOE, lacked good mechanism to make sustainable innovation; it lost its market leader position to late Huawei and ZTE. In 1993, ZTE launched out digital product ZXJ2000 for rural market, while Huawei developed its own digital product C&C08 in 1995. Both of these two firms have a much more quick response to the market needs and focus on low-end market. It is also important to note that the later development of other types of digital switches by firms such as Datang, ZTE and Huawei after the development of HJD-04 in 1991, all benefited from knowledge diffusion via inter-firm mobility of skilled engineers. For instance, 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 due to its higher salary levels (Mu & Lee, 2005).

4.3. Ren Zhengfei and innovation capability of Huawei

Huawei has always invested heavily in R&D; its R&D expenditure has grown steadily from US$340 million in 2001 to US$480 in 2004, representing a growth of more than 41 percent. Although Huawei's R&D expenditure represents only a small fraction of its total sales revenue in comparison with global telecommunication giants like Motorola, Nokia and Alcatel (see Table 2); it has, however, a very strong R&D commitment. For instance, in 2004, 48 percent of its 24,000 employees engaged in R&D. Its engineers are highly trained, with many holding doctoral qualifications. Huawei's R&D laboratories are also strategically located not only in China but around the world (see Table 3).

Huawei's high internal R&D investment is directly due to its founder's resolve to increase the firm's innovation capability. Ren Zhengfei, Huawei's founder and also sole leader, considered that "exchange market with advanced technology" policy would lead to the loss of the domestic market to the foreign firms. Hence, from very beginning, Ren Zhengfei aimed to build Huawei into a world-class and technologically advanced telecom-equipment provider. He sets up goals for Huawei *"to develop internal technological capabilities, to closely follow the development of global cutting edge technology, to stipulate self-development, to increase domestic market share, and over time to investigate the global market and compete against MNCs"*.

Table 2: Huawei's R&D compared with global telecommunication giants (2002-2004)

	2002			**2003**			**2004**		
Telecom manufacturer	**Sales** (US$ billions)	**R&D** (US$ billions)	**% of sales**	**Sales** (US$ billions)	**R&D** (US$ billions)	**% of sales**	**Sales** (US$ billions)	**R&D** (US$ billions)	**% of sales**
Huawei	2.67	0.36	13.5	3.83	0.39	10.2	5.58	0.48	8.6
Motorola	26.7	3.8	14.2	21.7	3.8	14.0	31.3	3.1	9.9
Nokia	30.8	3.1	10.1	36.2	4.6	12.7	39.1	5.0	12.8

Alcatel	17.4	2.2	12.9	14.3	1.8	12.6	15.3	2.0	13.1
Lucent	12.3	2.3	18.7	8.5	1.5	17.6	9.0	N.A.	N.A

Source: Company Reports

Table 3: Highlights of Huawei's innovation capability

Highlights:
• 10% of sales revenue spent on R&D, of which 10% spent on advanced research
• 48% of employees engaged in R&D
• Member of 70 standard organizations
• Global R&D centres are located in : Stockholm, Sweden; Dallas and Silicon Valley, U.S.; Bangalore, India; Moscow, Russia; Shenzhen, Shanghai, Beijing, Nanjing, Xi'an, Chengdu, and Wuhan, China.
• Having obtained CMM5 certification, four of Huawei's research institutes are now on partnership with other leading institutes in the industry in terms of software process management and quality control
• Applied for a total of 19,187 patents, as of December 31,2006
• Awarded 2,742 patents as of December 31,2006
• 133 UMTS essential patents, amongst the world's top 5

Source: Huawei's Annual Report (2006)

As a purely Chinese company, Ren Zhengfei and his company are well respected by many Chinese because it has achieved great success not only in the domestic markets, but also in the global markets (see Table 4). It is important to note that Chinese government policies have played a crucial role in Huawei's development.

Table 4: Huawei's market performance (by April, 2006)

Market Performance
• No.2 by global optical network market share in 2006
• No.1 by global MSAN unit shipment for four successive years since 2003
• 74 million ports of HONET integrated access products sold to 60 countries and regions world wide
• Awarded " Broadband Infrastructure Vendor of the Year in Asia Pacific" by Frost & Sullivan in 2006

Source: Huawei's Annual Report (2006)

4.4. *Evidence from Huawei's development experiences*

In this section, we present the evolution of technological learning process and catch-up experience of Huawei Technologies Corp., which is now China's biggest telecomm-equipment manufacturer. Huawei is making outward-bound FDI in new modes of technological learning, beyond the traditional channels of equipment purchases and technology licensing. This case study shows that how indigenous companies in latecomer industrializing countries like China can overcome the late mover position in some of the advanced markets they have entered.

4.4.1 A leader of 3G and ALL IP based FMC solutions

Chinese domestic manufacturers, including Huawei, take part in global system for mobile communications (GSM) area much later than the foreign giant multinationals. However, Huawei has attained astonishing success in the value-added part of GSM, such as integrated gateways, mobile intelligent networks and General Packet Radio Service (GPRS). As a follower in the area of GSM, Huawei has upgraded itself to keep pace with the global development of 3G and introduced “Code Division Multiple Access (CDMA) 2000 1XEV-DO” with speeds up to 2.4 Mbps in 2002. During the same year, it had a series of achievements with Wide brand Code Division Multiple Access (WCDMA) and became a leader in 3G technology.

In 2006, Huawei has been rising from a 3G technology leader to a market leader with its strong competitive abilities and leading advantages in the new-generation UMTS/HSPA Node B. According to its annual report (2006), Huawei won 32.9% of market share in the new UMTS/HSPA markets. The new-generation UMTS/ HSPA Note B has been widely deployed around the world, with a 44% of global unit shipment market share by the end of 2006. Vodafone chose Huawei to construct its commercial UMTS/HSDPA network in Spain and signed a 3G handset strategic partnership agreement with Huawei. Huawei also deployed Japan’s first IP-based HSDPA network for EMOBILE (Huawei’s Annual Report, 2006).

Moreover, for operators, the key to future successes is to transform the existing telecom network into more adaptable, cost-efficient ALL IP networks and realize fixed and mobile convergence (FMC) based on the transformation. ALL IP based FMC is to become a development trend of telecom network in the coming years. In this context, Huawei launched its ALL IP-based FMC solutions in 2006. With years of experience and strong innovation capabilities, Huawei has achieved a balanced development and effective convergence of fixed networks, mobile networks, IP technologies and telecoms VAS. It is now rank among the top three in all major areas of industry and is an operators’ best partner in the age of ALL IP and FMC. In terms of data communication, Huawei is the first in the industry to provide a “multi-service edge node” solution that supports FMC.

The success of Huawei’s catching-up relies on its rapid and precise reaction and more important, its self-developed technology. For instance, in 1999, China Mobile put forward a plan of prepaid fees for cell phones. The foreign telecom-equipment manufacturers were incapable to offer the system or reacted unwillingly. Huawei developed the system needed within a very short period of time due to its accumulated R&D experience in GSM. Within several months, this new product (mobile intelligent network) overlaid the existing networks, and had over 30 million users and monopolized China’s domestic market for a while. Later, Huawei’s mobile intelligent network became popular in Southeast Asian countries as well (China Electronic News, 2003).

4.4.2 External Alliances of Huawei

In a liberalising telecommunication sector, China's telecommunication manufacturers need to change the way they manage their resource dependence. Huawei participate actively this process of liberalisation in order to manage their local and global R&D technical joint venture, marketing alliances, mergers and acquisitions. In the context of conflicting technical, political and economic imperatives, Huawei has attempted numerous global technical, marketing alliances, joint ventures and acquisitions activities (see Table 5).

Table 5: Huawei's major technical alliances, joint ventures, and marketing and distribution agreements

• **October 2002**	Set up 3G Mobile Internet Open in Shanghai with NEC (Japan) to create an open platform to support 3G development in China
• **October 2002**	Signed a strategic agreement with Microsoft (USA) to set up a joint laboratory at Huawei's head office in Shenzhen, incorporating Microsoft's strength as a software innovator and Huawei's telecommunication expertise
• **March 2003**	Reached agreement with Nokia (Finland) on patent cross-license of WCDMA related technology products, covering the manufacturing and sales of WCDMA infrastructure equipment globally
• **March 2003**	Committed to a $US160 million joint venture with 3Com (USA) to manufacture and market low-end routers.
• **April 2003**	Signed a strategic partnership agreement with LightPointe (USA) on free space optic (FSO) technology
• **July 2003**	Partnership agreement with Avici Systems Inc. (USA) in IP market datacom solutions
• **03'**	Huawei acquired US-based optical communication technologies firms Cognigine and Optimite
• **September 2003**	Joined forces with Infineon Technologies (Germany) to offer a competitive WCDMA mobile phone platform
• **February 2004**	Signed and committed to a US$100 million joint venture with Siemens (Germany) to develop, market, and manufacture TD-SCDMA technology
• **May 2005**	Signed a mutual distribution agreement (MDA) with Marconi (UK) that will allow the two companies to resell parts of each other's products
• **August 2005**	Marconi (UK) begins talks with Huawei that could lead to a takeover by Huawei

Source: Huawei's press releases (2002-2005)

Huawei has been an active and willing participant in the global alliance process. Despite its relatively low R&D spending and weak global branding, major telecom giants continue to seek out Huawei. One important reason is that the telecom giants are motivated by the prospect of selling their products into the growing Chinese market. As StarHub's head of Network and Wholesale commented following:

"We have been impressed by Huawei's 3G technology roadmap, especially their ability to deliver next-generation wireless applications and services quickly. We are confident that Huawei's solution will help us deliver an enhanced 3G experience to our customers."

Mr. David Storrie,

StarHub's Head of Network and Wholesale

4.5. Leapfrogging catch-up in TD-SCDMA

As Chinese companies have been locked out of existing GSM network, the government and researchers have got a strong pressure to leapfrog the next generation technology to have China's own 3G standard. In 1994, two Chinese overseas, one work for Motorola, the other in University of Texas developed a new wireless network technology to surpass Qualcomm's technology. They set a joint venture with Datang, a former government research institute, Research Academy of Post and Telecommunication in 1995. In the same year, a new technology was invented by this mixed research group: TD-SCDMA (Time Division – Synchronous Code Division Multiple Access). It used new technology that represents future directions for wireless communications. Compared with other mobile system, TD-SCDMA can support dense services in populated areas better than others. It specially suits to handing asymmetrical IP data services because it is competent for adjusting data transmission rates with uplink and downlink. Moreover, adoption of Smart Antenna technology decreases transmission power in TD-SCDMA system and dramatically lowers the cost of the system products.

In May of 2000, TD-SCDMA, proposed by Datang Telecom Technology, was accepted by the Institute of Electrical and Electronic Engineers (IEEE) as one of the 3G mobile telecommunication standards. However, TD-SCDMA has much less support and R&D investment compared to other standards in the earlier time. It wasn't until October 23, 2002 that the Chinese government decided to support the new technology. The Ministry of Information Industry (MII) announced that it allocated 155 MHz of TDD resource to TD-SCDMA and a total of 120 MHz symmetrical FDD resource to WCDMA and CDMA2000 (60 MHz each). Besides that, three government agencies – the State Development and Reform Committee, National Science and Technology Department and MII together supported a "TD-SCDMA Industrial Alliance". The partners of this "TD-SCDMA Industrial Alliance" are as follows (Liu, 2007):

- System equipment: Datang, Siemens, UT Starcom.
- Network equipment: Siemens, Huawei, ZTE.
- End product chip: TI, Philips, ST microelectronics.
- End product: Samsung, LG, Hauli, Lenovo, etc.

Compared to WCDMA and CDMA, which have over a decade of experience, TD-SCDMA has only several years of history. However, its speed of development is much faster that the other two (Fan, 2006). Having China's own 3G standard makes it possible for domestic firms not only pay no patent fee for TD-SCDMA, but also be offered a much lower fee using other standards. The whole Chinese society takes TD-SCDMA as a national hero in IT industry. This climate will help TD-SCDMA again to get a favour in future 3G markets.

5. Findings and Discussion

5.1. The Propositions

Proposition 1. The innovation capability and self-developed technologies are the keys to domestic firms' catching up with the MNCs.

The study found that innovation capability and self-developed technologies have been the key to leading domestic firms in catching up with the MNCs. This finding is substantiated by the two examples about the development experience of Huawei and the exemple of Datang in the development of China's own 3G standard. This proposition has also been substantiated by the study of Fan (2006). She adopted a simple liner regression model to investigate the relationship between "leadership of the telecom-equipment industry" and "innovation capability. Her study indicated that innovation capability has a strong explanatory power to leadership position of domestic firms in the industry.

Proposition 2. The domestic firms in late-industrialized countries should develop their innovation capability even during the earlier stages of catching-up process.

Should the domestic firms in late-industrialized wait until they are at the last-stages of their catching-up to develop their innovation capability? This question has been highly debated by literature regarding late-industrialization. Hobday (1995) argued that East Asian Newly Industrialized countries follow the linear model that goes from cheap labor assembling, to the second stage of original equipment manufacturing (OEM), then to original design manufacturing (ODM) and finally to original brand-name manufacturing (OBM). This linear model implies that innovation capability will not play a significant role until the later stages of catching-up. However, our study shows that latecomers can catch-up with more advanced countries by leapfrogging or direct innovation at the technological frontier, as illustrated by the catching-up of Huawei's development in 3G, UMTS/HSPA Node B and ALL IP based FMC, the leapfrogging catching-up in TD-SCDMA by Datang.

Proposition 3. In-house R&D development supplemented with external alliance is a major means for leading domestic firms to build their innovation capability.

Generally, there are two major channels for the domestic telecom-equipment manufacturers improved their innovation capability: in-house R&D development and external alliance. Our study showed that in-house R&D has turned out to be the most important channel for domestic firms to improve their innovation capability. In fact, domestic telecom-equipment manufacturers firms have invested heavily in R&D activities, much more than most of the other electronics companies, such as Lenovo, Haier, TCL and MNCs in China's telecom-equipment market (see Table 6 & 7).

Table 6: Top 5 Chinese Electronics Companies' R&D spending (2000-2006)

	2000	2001	2002	2003	2004	2005	2006
Huawei	2.07	3.05	3.06	3.18	3.97	4.46	5.87
ZTE	0.54	1.13	1.18	1.33	2.25	1.96	2.83
Haier	1.57	3.98	4.00	3.85	4.36	4.57	6.73
Lenovo	0.86	0.96	1.08	1.16	1.18	1.50	2.80
TCL	0.45	0.59	0.88	1.29	1.41	1.95	1.90

Note: in billion Yuan
Source: MII (2007)

Table 7: Top 5 Chinese Electronics Companies' R&D spending (% of revenue)

	2000	2001	2002	2003	2004	2005	2006
Huawei	13.62%	18.79%	17.77%	14.67%	12.6%	9.26%	8.91%
ZTE	11.94%	10.34%	9.48%	7.62%	9.91%	9.08%	12.3%
Haier	3.86%	6.60%	5.63%	4.77%	4.29%	4.39%	6.23%
Lenovo	3.01%	2.92%	3.03%	2.88%	2.81%	1.39%	2.02%
TCL	2.54%	2.78%	2.75%	3.38%	3.35%	3.74%	4.06%

Note: in billion Yuan
Source: MII (2007)

Huawei and ZTE, as leaders in innovation capability, each invested 8.91 and 12.3 percent of their revenues in R&D in 2006. Since 2002, the two companies have been listed by MII as the top two in terms of "R&D spending as percentage of revenue" of China's 100 top electronics companies. It is comparable to leading MNCs, whose average R&D spending was 14% of the revenue in 2006. Moreover, leading domestic telecom-equipment manufacturers (Huawei, ZTE, Datang and Great Dragon) had 48, 44, 35, 58 percent of their employee engaged in R&D in 2006, respectively. It is much higher than most telecom giants' operations in China.

In terms of workforce's education level, these four leading telecom-equipment companies also have the most educated workforce in China. Each of them has a staff of over 70-80 percent educated up to the bachelor's degree level and 20-60% educated up to the Master's degree level or higher. Additionally, these four companies invest heavily their R&D facilities. Huawei and ZTE, for example, have more than ten R&D centers in China and abroad. Datang has two R&D centers, are located in Beijing and Shanghai, respectively; while Great Dragon has only one R&D center in Beijing. Huawei's global R&D centers are located in : Stockholm, Sweden; Dallas and Silicon Valley, U.S.; Bangalore, India; Moscow, Russia; Shenzhen, Shanghai, Beijing, Nanjing, Xi'an, Chengdu, and Wuhan, China. For ZTE, since 1986, it has built 12 R&D facilities within and outside China, these R&D centres and joint laboratories have enabled ZTE to utilize the skilled labour pool of the locations and continue to learn from its technologically advanced partners.

Our study also shows that external alliance can facilitate the building of innovation capability. However, that is only complementary to the internal development. Even though all these four companies have joint R&D facilities with domestic and foreign companies and institutes, most foreign cooperation started in the later stage of their development.

5.2. Patterns of catch-up in China's telecom-equipment industry

The work of Lee and Lee (2001) has identified three patterns of catch-up. First, "path-following" catching-up, that is, latecomer firms follow a path that is identical to that of pioneer, but go long this path with a shorter period of time. 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. The third pattern involves a "path-creating" catching-up, which means the latecomer firms explore their own path of technological development. The "path-following" catching-up is the most traditional pattern, while both "stage-skipping" and "path-creating" catching-up pattern have some aspects of leapfrogging.

In our study, we found that there are two different catching-up patterns in China's telecom-equipment industry. One is "path-following" pattern driven by using new technology in low-end market. For example, even Huawei takes part in GSM area much later than the foreign multinationals; the company has attained astonishing success in the value-added part of GSM, such as integrated gateways, mobile intelligent networks and General Packet Radio Service. Moreover, Chinese companies are good at innovation for low-end market, which help them to go global to access international low-end market. The other pattern is "stage-skipping" catching-up which tried to leapfrog some stages to the next generation technology. This finding is substantiated by two examples. The first example is concerned with the development of China's own 3G Standard (TD-SCDMA) by Datang. It shows that indigenous companies in latecomer countries like China can overcome the late mover position in some of the advanced markets and create a new path after having followed the path of pioneer. The other "stage-skipping" catching-up occurs in the market of electro-mechanical switches; even China had only little experience of producing electro-mechanical switches, but skipped the development and production analogue electronic switches to jump directly to the digital automatic switches. It seems that leapfrogging strategy will meet more challenges and problems than path-following. For instance, TD-SCDMA technology is still undergoing small scale of testing for further improvement. Datang has already spent more than two billion yuan for this technology. Most of money came from state-owned bank loan. Who will spend more money to finish the testing and improving before the final use is still unclear. The operators and government cannot fully decide before all the tests are finished (Liu, 2007).

6. Conclusion

This study has examined the growth of Chinese firm's innovation capabilities in the telecom-equipment industry. Through the case studies of Shanghai Bell, Huawei, ZTE, Datang and Great Dragon, it analyzes how catching-up in the telecommunication industry was realized. The first case shows that the knowledge diffusion from Shanghai Bell and its absorption by public research institutes was critical in the stage of phone digital switches catching-up. The second case in point is concerned with Huawei's outlook on in-house R&D development: it shows how Ren Zhengfei, the founder of Huawei, insisted on constructing the firm from the ground up and relying on its own innovation capability, thus giving Huawei a competitive advantage in later stages. The third example gives a demonstration of how Huawei, a latecomer in GSM, innovate in the low end market and used its local advantage and innovation capability to achieve unforeseen success in the value-added part of GSM and upgraded itself to keep pace with the global development of the 3G in later stages and network solutions for operators around the world. The last case illustrates that how leapfrogging catching-up has occurred in the development of China's own 3G standard: TD-SCDMA. The major findings of this study may be summarized as follows.

First, the innovation capability and self-developed technologies have been the key to leading domestic firms in catching-up with the MNCs *(proposition 1)*. As a result, this research suggests that domestic firms should prioritize building innovation capability from the very beginning to build up their competitiveness and hence to survive the competition with the MNCs as well as other domestic firms *(proposition 2)*.

Second, this research also finds that leading domestic firms mainly depend on in-house R&D development, supplemented with external alliance to build their innovation capability *(proposition 3)*, because the latter's effectiveness is conditional on the strength of the former.

Third, there are two different catching-up patterns in China's telecom-equipment industry. One is path-following in GSM driven by using new technology in low-end market. The other is leapfrogging in digital switches market and development of China's 3G standard (TD-SCDMA). Moreover, Chinese domestic firms were able to keep their competitive advantage due to the segmented nature of telecom-equipment markets. The rural market enables domestic firms to realize their first-stage growth.

Fourth, FDI can be a positive factor for catching-up in developing country for providing frontier technology and diffusion of knowledge. The case of Shanghai Bell shows that China took advantage of its large market size to push Alcatel's BTM into a contract enabling technology transfer. The Chinese side was able to acquire a related technology of manufacturing, installing and engineering through the establishment and operation of Shanghai Bell. So our study confirmed that knowledge diffusion from Shanghai Bell and other joint venture to domestic firms was critical for catching–up in China's telecom-equipment industry.

Fifth, the case studies also confirmed external factors that may be influencing the improvement of domestic firm in their innovation capabilities. These external factors consists of active role of government, clustering of R&D functions, an industry trend moving toward configuration technology, and sub-sector linkages. Our study finds that the government can play an important role in accumulating knowledge-based assets and diffusing knowledge to related field, which is significant for domestic firms aiming to increase the innovation capabilities. For example, indigenous Chinese firms, such as Huawei and ZTE were given active government support at the earlier time until they were developed enough to compete directly with foreign JVs in urban or coastal regions. Moreover, the role of government is also confirmed very critical for the leapfrogging catching-up in TD-SCDMA.

Based on the previous researches about technological learning, innovation and catch-up in the NIEs, this study provides a comprehensive elaboration in Chinese telecommunication industry. But our research is a single industrial case study. 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.

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