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Catching up through developing innovation capability: evidence from China's telecom-equipment industry

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Abstract

The significance of the innovation capability of domestic firms in late-industrialized countries is highly debated in the literature. This research studies the history of China's telecom-equipment industry from the middle of 1980s to 2002, with a focus on the innovation capability development of four domestic firms: Huawei, ZTE, DTT, and GDT.

The research finds that innovation capability and self-developed technologies have been the key to leading domestic firms' catching up with the multinational corporations. This finding is substantiated by both regression analysis between 'leadership of the telecom-equipment industry' and 'innovation capability' and development experience at the company level.

This research emphasizes that domestic firms should prioritize building innovation capability from the very beginning to build up their competitiveness and to survive the competition with the multinational companies as well as other domestic companies. It also suggests that domestic firms should focus on in-house R&D development to build their innovation capability, supplemented with external alliances.

Keywords: Innovation; Domestic firms; China; Telecom-equipment

1. Introduction

Is innovation capability necessary for latecomers? Should the domestic firms in late-industrialized countries wait until they are at the late-stages of their catching-up to develop their innovation capability? These are questions highly debated by literature regarding late-industrialization. Some argue (Hobday, 1995) that East Asian Newly Industrialized economies 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). Similarly, the bottom-up model (Leonard-Barton, 1995) has been used to describe the import substitution, which starts from import kits, progresses to localization of parts and components, then to product redesign, and finally to the stage of product design. These linear models imply that innovation capability will not play an essential role until the later stages of catching-up.

However, others argue that innovation capability could itself serve as a cause to catching-up. The fact that every country is a beginner for the newly emerging techno-economic paradigm (Schumpeter, 1942) implies that latecomers can catch up with more advanced countries by leapfrogging or direct innovation at the technological frontier (Perez, 1985), as was illustrated by the catching up of Korea's CDMA mobile phone industry (Lee and Lim, 2001).

The answer to the question 'Should the domestic firms in late-industrialized countries develop their innovation capability during the earlier stages of the catching-up process?' is particularly relevant to domestic firms and governments in the latecomer countries. If the domestic firms realize that innovation capability is pertinent to the firms' development even at the earlier stages of the catching-up process, their strategy will be quite different from the otherwise situation. Similarly, if innovation capability does affect catching-up even at the earlier stages, governments in latecomer countries

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List of Abbreviations

Companies and Organizations

BUPT	Beijing University of Posts and Telecommunications
DDT	Datang Telecom Technology Co., Ltd
GDT	Great Dragon Telecom
IEEE	Institute of Electrical and Electronic Engineers
ITU	International Telecommunications Union
MII	Ministry of Information Industry
PTIC	Posts and Telecommunications Industry Corporation
ZTE	Zhongxing Telecom Equipment Corporation

Technical Abbreviations

CDMA	Code Division Multiple Access
FDD	Frequency Division Duplex
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication (cellular phone technology)
R&D	Research and Development
TDD	Time Division Duplex
TD-SCDMA	Time Division-Synchronous Code Division Multiple Access
WCDMA	Wideband Code Division Multiple Access
3G	Generation (mobile communications)

Other Abbreviations

MNC	Multinational Corporations
OBM	Original Brand name Manufacturer
ODM	Original Design Manufacturer
OEM	Original Equipment Manufacturer
RMB	Renminbi, Chinese currency, US $1 is approximately 8.28 RMB (2002)

will accordingly set up corresponding agenda and implement industrial policies that encourage innovation.

Reviewing the development history of China's telecom-equipment industry, I notice that domestic manufacturers have achieved remarkable success in catching up vis-à-vis the multinational corporations (MNCs) in terms of gaining domestic market share. In this paper, I present evidence demonstrating that innovation capability developed by the domestic telecom-equipment manufacturers has been a driving force for the catching up with the MNCs and has also determined who the leading domestic firms in the industry are. Acquiring innovation capability here refers to improving the ability for innovation and self-developed technologies, which is in direct contrast to the strategies of imitating or assimilating obsolete technologies of more advanced countries.

This paper is based on 2-year worth of research of China's information and communication industry (Fan, 2003). In this paper, I examine the development history of China's telecom-equipment industry from the middle of 1980s to 2002, with a focus on four domestic firms. I use a multi-case approach for this research, supplemented with simple regression analysis. I organize the rest of the paper as follows: Section 2 introduces global telecom-equipment industry and the development of China's telecom-equipment industry. Section 3 exhibits findings from this research. Section 4 discusses channels for acquiring innovation capabilities of the domestic firms, both internally and externally. Section 5 states the conclusion and policy recommendation.

2. China's telecom-equipment industry

2.1. Global telecom-equipment industry

The telecom-equipment industry is one of the most R&D intensive-industries, with leading multinational corporations (MNCs) spending on average between 10 and 20% of their revenues in R&D in 2003 (MIT Technology Review, 2003). Corresponding to its R&D intensity, strong sub-sector linkage and specialization are the two main characteristics of the industry. Telecom-equipment manufacturing can be roughly divided into five sub-sectors: optical transmission systems, switch systems, access systems, data communication systems, and mobile communications. Several companies, such as Alcatel, Nortel, Motorola, and Lucent, lead in at least two sub-sectors; while companies like Cisco or Nokia are very specialized in data communication and mobile communication, respectively (Table 1). This implies that a similar technological base exists for different sub-sectors so that when a company excels in one sub-sector, it is comparatively easier for it to diversify into, and do extremely well in, another sub-sector. Meanwhile, some companies choose to specialize in only one area, such as Cisco or Nokia to fully utilize their advantage.

Table 1
Leading firms of the Global Telecom-equipment Industry, 2001

Sub-sectors	Leading firms (Top three)
Optical transmission systems	Alcatel, Lucent, Nortel
Switch systems	n.a.
Access systems	DSL: Alcatel, Siemens, Lucent Cable Modem: Motorola, Toshiba, Ambit
Data communication	Router: Cisco, Juniper Networks Ethernet switch: Cisco, Nortel, Enterasys
Mobile communication	Ericsson, Motorola, Nokia, Lucent

Source: summarized from various sources. DSL stands for Digital Subscriber Line. n.a., not available.

2.2. China's telecom-equipment market

China's telecom-equipment market is one of the fastest growing ones as well as one of the most competitive ones in the world. China's telecommunication infrastructure has experienced tremendous advancement in the past two decades as the government has given great priority to strengthen it to meet the accelerated growth in demand for telecom services. Fixed capital investment increased nearly 200 times during the two decades. The switchboard capacity grew more than 40 times—from 4.43 million lines in 1980 to 178.26 million lines in 2000 (MII, 2003). Accordingly, the numbers of both fixed-line and mobile phone subscribers have grown exponentially. The number of fixed-line subscribers increased more than 70 times during that period—from 2.14 million to 144.83 million (MII, 2003). From 1990 to 2000, the number of mobile phone subscribers jumped astonishingly 4700 times—from 0.02 million to 84.53 million users, which creates a remarkable average growth rate of 141% per year (Wong, 2002).

Echoing the market growth, most of the global leading firms started their operations in China in the 1980s and 1990s: Cisco, Ericsson, Lucent Technologies, Motorola, Nokia, Nortel Networks, and Siemens. Among the seven MNCs, Siemens and Motorola have the most employment (20,000 and 13,000, respectively). Motorola distinguishes itself by its large investment in China. By 2002, it had invested $3.4 billion since it first established subsidiaries in China back in 1987. Among all seven MNCs, it also had the highest sales revenue ($5.7 billion) in 2002 (Table 2).

Table 2
Major multinational corporations in China's telecom-equipment industry, 2002

Company name	Year entering China	Employment	Investment amount in China (in billion US$)	Sales (in billion US$)
Alcatel China	1983	6500	0.8	2.0
Cisco Systems China	1994	300	n.a.	1.0[a]
Ericsson China	1985	4500	0.6	1.7[a]
Lucent Technologies China	1993	3000	n.a.	n.a.
Motorola China	1987	13,000	3.4	5.7
Nokia China	1985	5000	20	2.9[a]
Nortel Networks China	1972	2600	n.a.	1.6[a]
Siemens China	1994	21,000	0.5	3.5

Source: summarized from various sources: Chinanex, 2003; Alcatel China, 2003; Cisco China, 2003; Ericsson China, 2003; Lucent China, 2003; Motorola China, 2003; Nokia China, 2003; Nortel Networks China, 2003; Siemens China, 2003. n.a., not available.
[a] Figures of 2001.

2.3. Chinese domestic firms

The presence of MNCs has facilitated the building of China's telecommunications infrastructure; however, it has posed great challenges for domestic firms as well. In the 1980s, China relied on 100% of its acquisition of telecommunication equipment through imports (Zhang, 2000). Despite the challenges, domestic firms have advanced rapidly. China, however, has progressed from being far behind in every sub-sector in the 1980s, to catching up in the switch market in the middle 1990s, to capturing the access market in the late 1990s, and to becoming competitive in the markets of optical transmission, data communications, and mobile communications in the new millennium.

The growth of major domestic manufacturers in the telecom-equipment industry constitutes a significant portion of the history of the industry. I used the following four domestic firms as my primary candidates to examine the development of the industry: Huawei, ZTE, DTT, and GDT. Chinese people use the term 'Great China' to describe those four companies, because if you combine the first characters of the companies' names in the reverse order (Ju-Great Dragon, Da-DTT, Zhong-ZTE, Hua-Huawei), you will create the phrase 'Great China' in Chinese. The phrase reflects China's pride in these domestic companies that have risen quickly and competed confidently with the giant MNCs.

Huawei and ZTE were established in the middle of the1980s, while DTT and GDT were established in the middle of the 1990s (Table 3). The size of Huawei and ZTE are much larger than that of DTT and GDT. For instance, Huawei and ZTE have over 22,000 and 12,000 employees, respectively, which is comparable to the workforces of the two largest MNC's in China, Siemens and Motorola, who have about 21,000 and 13,000 employees, respectively. In comparison, DTT and GDT only have about 4000 and 2500 employees, respectively. The revenue and profits of these companies also illustrates this size difference. The four

Table 3
Major domestic telecom-equipment manufacturers in China, 2002

Company name	Date of establishment	Employment	Sales revenue (in US$ billion)	Profit (in US $ million)
Huawei Technology Corporation (Huawei)	1988	18,000	2.7	319.8
Shenzhen Zhongxin Technology Corporation (ZTE)	1985	12,916	1.3	96.0
Datang Telecom Technology Co., Ltd (DTT)	1998	4183	0.247	36.1
Great Dragon Information Technology (GDT)	1994	2500	0.240	4.2

Source: Chinanex, 2003; Huawei, 2003; ZTE, 2003; DTT, 2003; GDT, 2003. Note, DTT and GDT's 'Sales Revenue' and 'Profit' were 2001's figure.

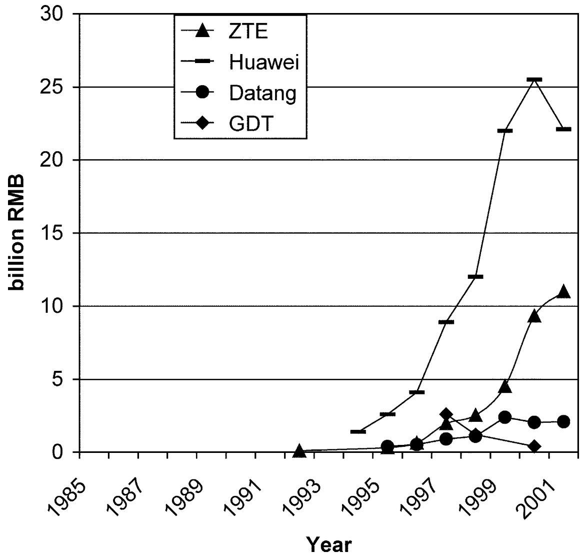

Fig. 1. Huawei, ZTE, DDT, GDT's, Revenue (1985–2002).

companies have similar major product ranges, but Huawei and ZTE have many more R&D and production facilities than DTT and GDT.

The revenue data (Fig. 1) illustrate the development path of these four domestic firms. The revenue paths of these major domestic firms, especially Huawei and ZTE, demonstrate the dynamic growth of the companies.

3. Findings

Through the case studies of the domestic telecom-equipment manufacturers, I found that innovation capability and self-developed technologies have been the key to their catching-up with the MNCs and have also determined who the domestic industrial leaders are. In the following paragraphs, I demonstrate the relationship between innovation capability and industrial leadership through both simple regression analysis and some examples at the company level.

3.1. Innovation capability and industrial leadership

I adopt the liner regression model to investigate the relationship between 'Leadership in the Telecom Equipment Industry' (dependent variable, *Y*) and 'Rank in Innovation Capability' (independent variable, *X*) The regression analysis results of the six leading domestic telecom-equipment producers shows an R^2 value at 0.69, indicating that innovation capability has a strong explanatory power to leadership position of domestic firms in the industry.

Strength in innovation capability and self-developed technology has determined who the domestic leaders are. Table 4 lists major domestic firms in the telecom-equipment industry. I evaluate companies' leading position in the industry by their sales revenue, ranked by the Ministry of Information Industry (MII, 2003). I created indexes of innovation capability for each of the companies by aggregating evaluations from specialists of the field, R&D input, and R&D output. The R&D input includes two indicators: firms' R&D spending as a percentage of the sales revenue and firms' R&D staff as a percentage of total employment. The R&D output includes indicators such as companies' patent numbers and participation in national S&T programs. Table 4 illustrates that a strong

Table 4
Major domestic telecom-equipment manufacturers: leadership and innovation capacity

Company name	Rank in tele-com-equip-ment industry	Rank in innovation capacity	Rank in R&D input	Rank in R&D output	R&D spending (% of Revenue) 2002	Profit (% of Revenue) 2002	Patent	R&D staff (% of employee) 2001	Employee with bachelor's or higher degree
Posts and Telecommuni-cat-ions Industrial Corp. (PTIC)	1	7	7	7	1.0	4.10	n.a.	n.a.	n.a.
Huawei Technology Corporation	2	1	1	1	18.8	16.4	271	46.50	85
Shenzhen Zhongxin Technology Corporation	4	2	2	2	10.3	7.3	217	46	72
Datang Telecom Technology Co., Ltd	5	3	3	3	12.3	2.9	7	41	93.87
Shanghai Bell Co., Ltd	3	4	6	4	5.3	13.1	19	n.a.	n.a.
Wuhan Telecommunication Science Institute	6	5	5	5	6.5	8.8	4	n.a.	n.a.
Changfei Optical Fiber and Optical Cable Co., Ltd	7	6	4	6	9.7	3.5	2	n.a.	n.a.

Source: MII, 2003; ('2002 Top 100 Chinese Electronics Companies' and '2001 Top 100 Chinese Electronics Companies'). PTIC, 2003; Shanghai Bell, 2003; State Intellectual Property Office of P.R. China, 2003; Note: (1) Even though Posts and Telecommunications Industrial Corporation (PTIC) had the highest revenue as a telecom-equipment industry in both 2001 and 2002, it has very low innovation capacity and its profit rate is 4.10%. Because PTIC's unique complicate structure and history (it is composed of many different factories that were belong to MII before), I did not include PTIC for regression analysis. (2) Huawei has gained 329 patents, according to Huawei as of June 27, 2003.

correlation exists between companies' leadership and innovation capability. For instance, Huawei, the leader in the industry (excluding PTIC), also heads in innovation capability.

The rest of the columns of Table 4 show a more detailed investigation of innovation capability of these companies. Domestic leading firms, such as Huawei, ZTE, and DTT, generally spend over 10% of revenue in R&D each year. For instance, Huawei spent 18.8%, ZTE spent 10.3%, and DTT spent 12.3% of their revenues in R&D in 2002. This level is comparable to the international R&D spending standard in the telecom-equipment industry, i.e. from10% to 20%. Furthermore, Huawei, ZTE, and DTT all achieved an 'R&D staff/total employment' ratio over 40%. Shanghai Bell, a joint venture with Alcatel and the Belgian government, though large in terms of size, has low innovation capability compared with its industrial leadership. Shanghai Bell spent only 5.3% of its revenue in R&D and the R&D staff was 31% of the total employment in 2002, significantly lower than other leading domestic firms.

Telecom-equipment MNCs in China have less R&D input than the domestic firms, measured by R&D spending as a percentage of revenue and R&D staff members as a percentage of employment in China. As mentioned before, multinational corporations that have a major presence in China are also global leaders in the industry. Table 5 compares seven major MNCs' R&D statistics worldwide and in China. These MNCs had an average global R&D spending of 15% of sales revenue, with Cisco, Ericsson, and Nortel as leaders (21.4, 20.1, and 18.7%, respectively) and Siemens and Nokia as distant followers (7.8 and 9.6%, respectively). In contrast, their R&D investment in their Chinese branches has been much lower than their Chinese peers, indicated by a lower R&D staff as a percentage of the total workforce.

3.2. Evidence from the companies

I would like to offer three examples to reveal how innovation capability has driven the domestic telecom-equipment companies to catch up to the MNCs. The first example is about Huawei's vision on innovation capability: it shows how Ren Zhenfei, the founder of Huawei, insisted on building innovation capability from the beginning and thus gave Huawei a competitive edge over others at later stages. The second example shows how Huawei used its local advantage and innovation capability to advance in the global system for mobile communications (GSM) and third generation mobile communications systems (3G) in later stages. The last example demonstrates the challenges that DTT has faced in building its innovation capability and why government support has been crucial for it to develop China's own 3G standard, TD-SCDMA.

3.2.1. Ren Zhenfei and innovation capability of Huawei

Huawei has always invested heavily in R&D For instance, it invested 18.8% of revenue in R&D in 2002, higher than any other domestic firm or any MNC in China in the telecom-equipment industry (MII, 2003). Huawei's high internal R&D investment is a direct result of its founder's determination to improve the company's innovation capability. Originally an army officer, Ren himself is definitely known to have personal charisma, reflected in his vision for his company, even though no media have been able to interview him since he started the company. As Huawei's founder and sole leader, Ren Zhenfei believed that the country's 'exchange market with technology' policy would lead to the loss of the domestic market to the MNCs. Not only were the Chinese unable to obtain foreign technologies, but domestic companies had also been put at a disadvantage (Xiao, 2002).

Table 5
Major multinational corporations in the telecom-equipment industry, R&D world-wide and in China

Company name	World-wide							China		
	R&D spending (in million of dollars)	Total revenue (in million of dollars)	R&D spending (% of Revenue)	R&D staff	Total employment	R&D staff (% of Employment)	R&D spending per employee (in dollar)	Employment in China	R&D staff in China	R&D staff (% of Employment)
Alcatel (France)	2567	22,698	11.3	18,700	99,314	19	25,845	6500	2000	31
Cisco (U.S.)	4777	22,293	21.4	n.a.	38,000	n.a.	125,711	300	n.a.	n.a.
Ericsson (Sweden)	4516	22,447	20.1	n.a.	85,200	n.a.	53,002	4500	n.a.	n.a.
Lucent (U.S.)	3520	21,294	16.5	n.a.	77,000	n.a.	45,714	3000	467	16
Motorola (U.S.)	4358	30,004	14.5	n.a.	111,000	n.a.	39,261	13,000	1300	10
Nokia (Finland)	2672	27,925	9.6	20,463	53,849	38	49,628	5000	300	6
Nortel (Canada)	3380	18,033	18.7	n.a.	53,600	n.a.	63,061	2600	110	4
Siemens (Germany)	6028	77,329	7.8	53,000	484,000	11	12,455	21,000	n.a.	n.a.

Source: MIT Technology Review, 2003; Alcatel China, 2003; Cisco China, 2003; Ericsson China, 2003; Lucent China, 2003; Motorola China, 2003; Nokia China, 2003; Nortel Networks China, 2003; Siemens China, 2003.

Thus, Ren set up goals for Huawei at the very beginning 'to develop the national industry, not to set up joint ventures with foreign companies, to closely follow global cutting-edge technology, to insist on self-development, to gain domestic market share, and to explore the international market and compete against international rivals.' Through these goals, Ren aimed to build Huawei into a world-class and technologically advanced telecom-equipment manufacturer from the very beginning. He ignored the lucrative stock and real estate businesses in the early 1990s and 'was stubborn enough to put all his eggs in one basket'—the heavy investment in R&D has ranged from RMB 80 million to over RMB 100 million per year in recent years. Even in the earlier years of Huawei, the company had a high R&D/employee ratio, namely, 500 R&D staff and only 200 production staff.

Ren Zhenfei and his company are well respected by many Chinese because Huawei, a purely Chinese company, has achieved great success in the telecom-equipment field, surpassing not only domestic peers but also many joint ventures set up by MNCs.

It is worth noting that Ren Zhenfei has been appreciative of government policies that have played a vital role in Huawei's development. Ren has commented (Xiao, 2002, p. 127) the following

> "…Huawei was somewhat naïve to choose telecom-equipment as its business domain in the beginning. Huawei was not prepared for such an intensified competition when the company was just established. The rivals were internationally renowned companies with assets valued at tens of billions of dollars. If there had been no government policy to protect [nationally owned companies], Huawei would no longer exist …"

3.2.2. Huawei in GSM and 3G

Domestic producers, including Huawei, entered into the global system for mobile communications (GSM) area much later than the MNCs However, Huawei achieved unexpected success in the value-added part of GSM, such as integrated gateways, mobile intelligent networks, General Packet Radio Service (GPRS), and short message centers. For instance, in the field of mobile data communication, such as short messaging, Huawei's equipment has more than 50% of the domestic market. The key to Huawei's success lies in its fast and precise reaction to customer requests and more importantly, its self-developed technology, as shown in the following examples. For instance, in 1999, China Mobile proposed a plan of prepaid fees for cell phones. MNCs were unable to provide the system or reacted reluctantly. Based on its accumulated R&D experience in GSM, Huawei developed the product within a very short time. The new product, the mobile intelligent network, can be conveniently overlaid with existing networks. Within several months, Huawei's mobile intelligent network equipment had over 30 million users and monopolized China's domestic market for a while. Even in 2002, it had around 80–90% of domestic market. Later, the product became popular in Southeast Asian countries as well (China Electronic News, 2003).

A follower in the area of GSM, Huawei has upgraded itself to keep pace with the global development of the third generation wireless communications system (3G). Huawei introduced 'Code Division Multiple Access (CDMA) 2000 1XEV-DO' with speeds up to 2.4 Megabits per Second (Mbps) in 2002. During the same year, it had a series of achievements with Wideband Code Division Multiple Access (WCDMA) (China Electronic News, 2003)

- At the beginning of 2002, Huawei passed the MTnet test.
- In June 2002, Huawei made a commercial terminal call based on the R99 protocol.
- In September 2002, in its Shanghai WCDMA external experimental network, Huawei successfully made the first world WCDMA intelligent call based on CALMEL III.
- In October 2002, it established China's first 3G Open Lab with NEC and introduced the smallest WCDMA large-scale base station to-date.
- In December 2002, at International Telecommunications Union (ITU), Huawei introduced WCDMA core network equipment based on soft switches.

Huawei's achievements came from its early start and heavy investment in 3G. As early as the end of 1995, Huawei started R&D in CDMA. In 1998 Huawei started to develop WCDMA products. From 1998 to May 2002 Huawei invested RMB 3 billion in WCDMA and its R&D staff totaled 3500, including people from its US, Swedish, and domestic R&D centers. It has since operated over 20 WCDMA experimental networks worldwide (China Electronics News, 2003).

3.2.3. DTT and TD-SCDMA

DTT, joined by Siemens, developed the Chinese 3G standard, Time Division-Synchronous Code Division Multiple Access (TD-SCDMA), which was accepted by the Institute of Electrical and Electronic Engineers (IEEE) in May 2000 as one of the third-generation mobile communications standards. TD-SCDMA used new technologies that represent future directions for wireless communications, such as synchronized CDMA, intelligent antennas, software-based wireless, and high-speed data transmission. Intelligent antennas and software-based wireless are unique to TD-SCDMA. In addition, TD-SCDMA is claimed to have high spectrum utilization because TD-SCDMA uses the Time Division Duplex (TDD) model and only needs a single channel for bi-directional communications (Communication World, 2002b). For instance, TD-SCDMA needs only 1.6 MHz of spectrum resources, while Wideband Code

Division Multiple Access (WCDMA) requires 10 MHz of bandwidth (5 MHz in each direction).

The current (2002) allocation of international 3G frequencies is actually to TD-SCDMA's advantage. In Europe, 3G frequencies have been auctioned for both Frequency Division Duplex (FDD) and TDD. In Asia Pacific, except for Japan and Korea which only auctioned FDD licenses, Singapore, Malaysia, and Taiwan auctioned both FDD and TDD, while Australia auctioned TDD and FDD to different service providers. The United States has cleared 31 MHz of frequency resources to be used for TDD in 2002, but even the largest continuous frequency segment available has only 4 MHz. Since WCDMA needs 10 MHz and CDMA 2000 needs 8 MHz for both directions, it seems only TD-SCDMA can use the current frequency resources for 3G in the United States.(Communication World, 2002a).

Compared to other standards, TD-SCDMA has much less support and R&D investment. For instance, WCDMA has 27 companies as main supporters, which includes NTT DoCoMo of Japan, Ericsson and Nokia in Europe. CDMA 2000 has most support from North America and Korea, such as Qualcomm, Nortel Networks, Motorola, and Samsung. Distinguished domestic companies, such as Huawei, ZTE, and Jingpeng, are also supporters of WCDMA and CDMA 2000. WCDMA and CDMA 2000 have invested $40 billion and $10 billion, respectively, in their development, while TD-SCDMA has only invested less than $1 billion. Further, worldwide, there are over 50,000 and 10,000 R&D staff at work on WCDMA and CDMA 2000, while there is less than 3000 for TD-SCDMA (Communications World, 2002c).

For a while, it seemed that the Chinese government had no special interest in this domestically produced standard and would put the three standards in a quite equal position; whereas the two incumbent operators, China Mobile and Unicom, seemed to favor the other two standards (GSM-GPRS-WCDMA and CDMA-CDMA2000 1X-CDMA2000 EV) over TD-SCDMA. DTT, a small company by international standards with only $0.2 billion annual sales revenue, therefore started a no-return journey by focusing almost all its attention on TD-SCDMA.

It was not until October 23, 2002, that DTT finally obtained signals of support from the government. The government was planning for the future expansion of TD-SCDMA, as indicated by an announcement made on that day. The Ministry of Information Industry (MII) announced[1] that it allocated 155 MHz[2] of TDD resource to TD-SCDMA and a total of 120 MHz symmetrical FDD resource to WCDMA and CDMA 2000 (60 MHz each). TD-SCDMA obtained 155 MHz asymmetric TDD ranges: 1880–1920, 2010–2025, and 2300–2400 MHz. In addition to the 55 MHz of the core frequency range assigned by IEEE, TD-SCDMA obtained the extended 100, 2300–2400 MHz, which used to belong to the military. This frequency division demonstrates the support of the Chinese government for TD-SCDMA, the Chinese 3G standard. Just one week later, on October 30, 2002, responding to this announcement, seven telecom-equipment manufacturers–Southern Hitech, Huali Group, Huawei, Legend, ZTE, China Electronics Group, and China PuTian Group–joined DTT to form the 'TD-SCDMA Industrial Alliance,' with the support of three government agencies—the State Planning Commission, MII, and the National Science and Technology Department (People's Posts and Telecommunications, 2002).

Having China's own 3G standard makes it possible for Chinese manufacturers not only to pay no patent fee for TD-SCDMA, but also to be offered a much lower fee using other standards. For first- and second-generation mobile communications, China paid billions of dollars in patent fees and other intellectual property fees related to the mobile standards. For instance, for every CDMA cell phone produced by Chinese manufacturers and every customer initialized by China Mobile, China needed to pay a $2 patent fee to Qualcomm. After the development of TD-SCDMA, nine companies from the WCDMA alliance announced that it would cap the cumulative royalty rate to patent holders for its Chinese partners to be less than 5%, much lower than for other countries (Economic Observation, 2003).

The cumulative royalty cap—which would apply both to mass market phones and network equipment—would limit the total patent-based royalty on any given item to 5% of the sale price, regardless of how many patents are involved (and who holds them) (Mobile Business Daily, 2002).[3]

Compared to WCDMA and CDMA, which have over a decade of experience, TD-SCDMA has less than a 3-year history. Though its speed of development is much faster than the other two, the commercialization will not be realized until 2004 or 2005. Furthermore, acquiring more technical expertise to work for the commercialization of TD-SCDMA is another task with which DTT has to deal. Considering TD-SCDMA uses the same core network, no development would need to be done for the core network part. DTT has developed the access equipment, and it plans to introduce it (including base station and its controller) to the market in the second-half of 2003. They will develop the chipset at the same time. DTT plans to have TD-SCDMA

[1] It is entitled as 'Announcement about the Third Generation Public Mobile Communication System Frequency Planning.'

[2] I note that many countries have assigned the core frequency range to either WCDMA or CDMA 2000. If TD-SCDMA only has part of the core frequency, it will be difficult to expand globally even if it is successful in China, thus unable to roam internationally. However, if the commercialization of the new expanded frequency range is successful, it will potentially affect other neighboring countries since the 2300–2400 MHz frequency range is free for most of them.

[3] In May 2002, Nokia proposed to promote the spread of Wideband Code Division Multiple Access (WCDMA) for 3G nets by capping the royalty rate paid to patent holders at 5%.

handsets appear in the market in the first-half of 2004 (Communications World, 2002c)

4. Discussion: channels for acquiring innovation capability

How have the leading domestic telecom-equipment manufacturers improved their innovation capability? Here I examine two major channels: in-house R&D development and external alliance. I found that in-house R&D development, supplemented with external alliance, is a major avenue for leading domestic firms to build their innovation capability.

Several external factors do affect the development of innovation capability at the firm-level. First, the government can play a positive role in accumulating knowledge-based assets, which is crucial for domestic firms aiming to acquire innovation capability. Further, Network clustering of R&D functions makes innovation easier as firms communicate and exchange ideas with the knowledge nucleus. The telecom-equipment industry is moving towards configuration technology and it is also acting as a catalyst for innovation in specific areas. On the other hand, sub-sector linkages have rewarded a company's effort by faster diversification into other sub-sectors.

4.1. Internal development

In-house R&D has turned out to be the most important factor for domestic firms to improve their innovation capability. Domestic leading firms have invested a large amount of capital and devoted a large percentage of their workforces in R&D activities, much more than most of the other electronics companies in China and multinational corporations in the telecom-equipment industry in China. First, domestic firms invested heavily in R&D; leaders in innovation capability, such as Huawei, ZTE, and DTT, each invested 18.8, 10.3, and 12.3% of their revenues in R&D in 2002, and were listed as the top three by MII in terms of 'R&D spending as percentage of revenue' of 'China's 100 largest electronics companies' in 2002 (MII, 2003). It is comparable to leading MNCs, whose average R&D spending was 15% of the revenue in 2002. In particular, Huawei has the highest 'R&D/Revenue' ratio among all four telecom companies. As the leader in innovation capability and the industry, Huawei was listed as the 7th largest electronics company in China by revenue, but its R&D expenditure topped all other companies listed in 'China's 100 largest electronics companies' in 2002.

Furthermore, leading domestic telecom-equipment companies (ZTE, Huawei, Datang, and GDT) had 42, 46, 30, and 54% of their workforce devoted to R&D in 2002, respectively. It is significantly higher than most MNCs' operations in China. For instance, Lucent, Motorola, Nokia, and Nortel each have 16, 10, 6, and 4%, respectively, of employees working in R&D.

An examination of the workforce's education level indicates that these companies probably have the most educated workforce in China. Each of the four companies has a workforce of over 70–80% educated up to the bachelors degree level and 20–60% educated up to the Master's degree level or higher. For instance, among Huawei's 22,000 employees, more than 85% have bachelors or higher degrees, and about 60% hold a master's or PhD degree.

According to one interviewee (a ZTE manager), MNCs have two disadvantages in R&D in China, which implies that domestic firms have two advantages. First, unlike major domestic companies, such as ZTE, Huawei, DTT, and GDT, foreign firms (joint ventures or wholly owned subsidiaries) do not have high-level R&D staff in China, but instead they are staffed mostly with marketing and local R&D people (for simple customization). This view is in line with the view of Amsden et al. (2000) that higher-level R&D, i.e. exploratory and advanced development, should be located close to production or markets. The reason could be that MNCs worry about the leaking of their tangible knowledge, especially in a country that has issues with enforcement of intellectual property. Second, while foreign firms are suffering separation of their marketing people from the core R&D staff in the home country, domestic firms have their marketing people closely connected with their R&D staff. Thus, once domestic firms grasp the needs of service providers through marketing people (and sometimes even through the R&D people themselves), their R&D departments can develop solutions and provide the desired products and services in a timely fashion.

Corresponding with a large investment in R&D are the R&D facilities of the companies. Huawei and ZTE both have over ten R&D facilities within China and abroad. DTT has two R&D centers in Beijing and Shanghai, while GDT has one R&D center in Beijing. Huawei has six R&D centers in Beijing, Shanghai, Nanjing, Hangzhou, Xi'an, and Chendu, as well as the Huawei Technology Center in its Shenzhen headquarters. Furthermore, Huawei has five overseas R&D offices: in Dallas and Silicon Valley in the United States, and in Sweden, India, and Russia. The Huawei India Software R&D Institute became the first Chinese company to obtain the certification from the CMM 4 International (Huawei, 2003).

These overseas offices connect the company closely with the latest developments in microelectronics and telecom technology. Since 1986, ZTE has built 12 R&D facilities within and outside China, these R&D centers and joint laboratories have enabled ZTE to utilize the skilled labor pool of the locations and continue to learn from its technologically advanced partners.

4.2. External alliance

External alliance can facilitate the building of innovation capability, however, that is only complementary to the internal development. For instance, even though all 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. Huawei has led in cooperation with international MNCs. Huawei has actively undertaken joint R&D laboratories with foreign companies, such as Texas Instruments (TI), Motorola, International Business Machines Corporation (IBM), Intel, Ageare, ALTERA, SUN, Microsoft, and NEC, focusing on various telecom technologies. In addition to its own R&D facilities, ZTE has joint laboratories with Beijing University of Posts and Telecommunications (BUPT), Motorola, and Xi'an Electronic Engineering Institute in China. Similarly, DTT has joint R&D activities with domestic and international partners, such as MII Beijing Design Institute, Electronics S&T University, TI, BUPT, and JAS South Korea, in addition to its two R&D centers in Beijing and Shanghai. GDT also has wide cooperation with different institutes and companies domestically and abroad, such as China HP, C and S Technology and Space from South Korea, etc.

In my view, Huawei, as well as ZTE and DTT, have utilized their cooperation with foreign MNCs who are leaders in late technologies as a complementary approach to developing its innovation capabilities in addition to its internal development. Chinese firms generally do not consider foreign cooperation as an effective tool for technological improvement, but consider that it may be used as a complementary tool. For instance, one of the senior R&D managers at Huawei's Beijing R&D center pointed out,

> "…Huawei does not view R&D cooperation with foreign companies as an effective mechanism to gain technological competitiveness," since "there is no reason for foreign firms to transfer their most advanced core technologies to a Chinese partner over whom they do not have management control." (Smith-Gillespie, 2001, p. 82)

This research supports Hu et al. (2003)'s findings of Chinese large and medium size enterprises, which pointed out that the contribution of technology transfer was found to be conditional on its interaction with in-house R&D.

5. Conclusion

To answer the research question 'Should the domestic firms in late-industrialized countries develop their innovation capability during the earlier stages of the catching-up process?' I have studied the development history of China's telecom-equipment industry from the middle of 1980s to 2002, with a focus of four domestic firms: Huawei, ZTE, DTT, and GDT.

I have found that innovation capability and self-developed technologies have been the key to leading domestic firms in catching up with the multinational corporations. This finding is substantiated by both regression analysis between 'leadership of the telecom-equipment industry' and 'innovation capability' and development experience at the company level. Furthermore, I observe that leading domestic firms mainly depend on in-house R&D development, supplemented with external alliance to build their innovation capability.

This research therefore stresses that domestic firms should prioritize building innovation capability from the very beginning to build up their competitiveness and to survive the competition with the multinational companies as well as other domestic companies. It also suggests that domestic firms focus on in-house R&D development to build their innovation capability, supplemented with external alliances, because the latter's effectiveness is conditional on the strength of the former.

The case studies have confirmed other external factors that have affected domestic firms' improvement in innovation capability. They include active role of the government, clustering of R&D functions, an industry trend moving towards configuration technology, and sub-sector linkages. The government can play a positive role in guiding and helping domestic firms to accumulate the innovation capabilities. Clustering of the R&D functions of the domestic firms can create a network effect for innovation. Further, targeting certain high-tech industries that are characterized by configurational technologies will facilitate the catching up through innovation, because the technologies allow great flexibility in development and application. Finally, sub-sector linkages can assist the process of catching up through specialization and diversification.

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