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Abstract

The telecommunication system industry has long been dominated by the Swedish giant, Ericsson. Huawei, a newly emerged firm from China, entered the industry, grew rapidly, and finally overtook Ericsson in terms of sales in 2012. Given the rarity of this phenomenon, this study seeks to explain how this became possible. We first verified that Huawei's market share catch-up is rather owing to its technological capabilities than its cost advantages. Then, our analysis of the European patents shows that Huawei grew rapidly by developing technologies that are different from those of Ericsson, and that the former relies more on recent and scientific knowledge in its innovation strategies. This study suggests that creating one's own technological path rather than following the path of the incumbents could be a viable strategy for successful technological catch-up.

KEYWORDS: Market shares; technologies, catch-up; Huawei; Ericsson; patents; a latecomer.

JEL Classification: O32, L63, O14

1. Introduction

The telecommunication system industry has long been dominated by several Western firms. In particular, the industry has been led by the Swedish telecommunication giant, Ericsson, followed by Siemens, Nokia, Motorola, Alcatel, Nortel, and Lucent. In the early 2000s, the industry faced a drastic decline in market demand because of the IT bubble burst. Although many incumbents suffered, Huawei, a private Chinese firm founded in 1987, successfully entered the global market, and achieved rapid growth. Huawei has accelerated its market shares since the mid-2000s, and in 2012, it finally overtook the long-standing industry leader, Ericsson, in terms of annual revenue.

Huawei's catch-up is distinct from those of typical Chinese firms in that it is not a state-owned but a private firm. Moreover, its success seems to have more to do with technological competitiveness than with low-cost labor; Huawei was ranked first globally based on the number of international patent filings through the Patent Cooperation Treaty (PCT) in 2008. Huawei's portable wireless access device, "Femtocell 2.0", won an iF Design award and a Red Dot design award in 2009, and its optical distribution network access terminal box, PIVOT, won a Red Dot design award in 2010. Fast Company ranked Huawei fifth among the world's 50 most innovative companies in 2010.

The Chinese government played a part in Huawei's accumulation of technological capability through the "trading market for technology" policy, which allowed China to gain access to telephone switching technologies via foreign direct investment in the 1980s (Mu and Lee 2005). In the 2000s, the Chinese government's support for TD-SCDMA as a third generation mobile telecommunication standard helped Chinese telecommunication equipment firms to establish indigenous innovation capabilities (Liu and Dalum 2009; Yu 2011). However, not all Chinese firms were as successful as Huawei; ZTE, the second-largest telecommunication equipment firm, has remained behind Huawei and the major incumbents (Kang 2014). Such situation indicates that the role of the Chinese government's policy was an important but not a primary factor in relation to Huawei's catch-up.

Hence, to explain Huawei's successful catch-up, Huawei's innovation strategies must be examined. The existing research has emphasized Huawei's intensive internal R&D, strategic R&D alliances, and R&D globalization (Yeung 2005; Huang 2006; Zhu 2008; Sun 2009; Zhang 2009; Zhu et al. 2009; Athreye and Chen 2010; Zhang and Duysters 2010; Gao 2011; Fan 2010). Since the 1990s, Huawei has invested more than 10% of its revenue

in R&D, and globalized its R&D by entering India, Sweden, and the United States, among other countries. In 2000, Huawei started establishing strategic R&D alliances with Texas Instruments, IBM, Motorola, Lucent, Intel, and Sun Microsystems, and joint ventures with NEC, 3COM, Siemens, and Nortel. Intensive internal R&D, R&D globalization, and strategic R&D alliances have undeniably contributed tremendously to Huawei's technological competitiveness. Given the heavy investment in R&D, a question emerges regarding the result of enormous amount of R&D as well as Huawei's specific innovation strategies.

This study focuses on the technological details of Huawei's catch-up strategy and raises a key research question of whether Huawei has caught up and finally forged ahead by using similar or different technologies from those of the forerunning incumbent. Using similar technologies implies that the latecomer simply attempts to imitate, whereas using different technologies indicates the pursuit of creating new technologies and taking a different technological path or trajectory from the incumbents. This contrast between similar and different technologies is interesting in terms of the literature on technological catch-up. Traditional or early studies, such as Lall (2000), Kim (1980), Westphal, Kim, and Dahlman (1985), and Hobday (1995), have observed that the latecomers tried to catch up with advanced countries by assimilating and adapting the incumbents' more-or-less obsolete technology. A contrasting view has been expressed by Lee and Lim (2001) and Lee (2013): the latecomer does not simply follow the advanced countries' path of technological development; rather, they sometimes skip certain stages or even create their own path that is different from those of the forerunners.

However, we have not found studies that quantitatively analyzed whether a latecomer firm catches up with forerunners in market share by relying on the same or different technologies. Moreover, no method has been suggested for such analysis. This study suggests an assessment method using patent citation data, and applies the method to the case of Huawei vs. Ericsson. Our choice of these two companies is not arbitrary because our objective is to compare a leading company and a latecomer firm under a situation where the latecomer firm eventually overtook the leading company. Thus, our analysis is different from that of Kang (2014), which has compared Huawei with a state-owned

Chinese company, ZTE.[1] Other latecomer firms that are also increasing market shares in diverse speed may exist, but they are not the target of our comparison. We choose a case in which catch-up in market share is completed to determine the necessary conditions of a successfully completed catch-up.

This paper uses the patent applications that Huawei and Ericsson filed in the European patents office between 2000 and 2010. The related citation data are used as well. Our analysis shows that Huawei's consistent accumulation of technological capability, rather than its cost advantage, has been the crucial factor in its successful catch-up. Furthermore, Huawei's catch-up is a result of its eventual success in creating its own technological trajectory, although it started by imitating the forerunner by integrating the same or similar technologies in the early stages.

Joo and Lee (2010) have compared the patent citation data of Samsung and Sony to examine the diverse aspects of technological catch-up. Similarly, we define and measure various patent-based variables, including the way in which they validate the comparability of the two rival firms in terms of the firms' patent portfolio. However, Joo and Lee (2010) did not include an explicit research question as to whether the latecomer (Samsung) had been catching-up with the forerunner (Sony) by developing the same or different technologies. As explained in Section 3, this study uses three explicit criteria, namely, quality of their patents, mutual-citations, and self-citations, to answer this research question. First, we examine the quality of the two firms' patents (measured by the average number of received citations) to determine whether the latecomer's patent quality catches up with or even surpasses that of the forerunner. Second, we examine the mutual citations between the two rival firms' patents to determine the degree of reliance on each other as source of knowledge. Third, we also examine whether two firms rely on the same sets of knowledge from the third party in their invention activities by measuring the 'indirect dependence' between two firms using the common citation ratios. Fourth, we examine the rival firms' degree of self-citation to assess the extent to which the latecomer firm has become independent of external knowledge sources and has become self-reliant on its own knowledge base (Lee 2013; Ch. 5).

[1] The present study is also different from studies on on-going catch-up, such as Lee et al (2016) that have used a large sample of firms from two countries.

The remainder of the paper is structured as follows. In Section 2, we provide a brief overview of Huawei and Ericsson, and then describe Huawei's catch-up in the global telecommunication equipment market. Section 3 discusses the data, methodology, and the hypotheses of this research. Section 4 analyzes Huawei's technological catch-up with Ericsson based on the three criteria to verify our key hypothesis. Section 5 addresses two additional aspects of comparison, such as citation lags and citations in non-patent literature. Lastly, Section 6 summarizes the findings and provides the concluding remarks.

2. Huawei vs. Ericsson

2.1 Basic Profiles of the Two Firms

Ericsson

Ericsson has been the undisputed world leader of the telecommunication equipment industry since the 1990s. Essentially, the history of Ericsson is also the history of the global telecommunication industry. This company was founded in 1879 by Lars Magnus Ericsson as a telegraph equipment repair shop in Stockholm, Sweden. In 1880, Ericsson started manufacturing its own telephones, and delivered its first telephone switch in Gävle, Sweden. The Swedish domestic market was limited and Televerket, the Swedish operator, provided all locally required equipment via its own equipment manufacturing division, Teli. Consequently, from as early as the 19th century, Ericsson reached out to the international market and won its first major foreign contracts in Norway and Russia in 1881. By 1900, it had produced 50,000 telephones and employed 1,000 people globally.

Ericsson introduced several significant innovations, such as the 500-point rotating switch in the 1920s, the 500-point crossbar switch in the 1950s, and the AKE 13 SPC switch in the 1960s. The 500-point rotating switches, which accommodated approximately 100 telephone systems (350,000 lines), were produced in the 1930s. Sales continued to rise during the 1940s, and were sustained until the 1970s (Ericsson 2014). Production of the 500-point crossbar switch began to exceed that of the 500-point rotating switch from the early 1960s, with cumulative production of the crossbar switch reaching one million by 1971. With the success of the 500-point crossbar switch, Ericsson became one of the major international telecommunication equipment manufacturers; in 1970, it had 50,000 employees in 26 different companies in 15 countries (Fridlund 1999). The AKE 13 was the world's first multi-processor SPC switch with modular software architecture. AKE switches

were not commercially successful because they were expensive and their technological capacity was limited; however, these switches laid the foundation for Ericsson's technological breakthrough in the 1970s – the AXE switch.

In 1970, Ericsson formed a research joint venture with Televerket and started to develop digital switches. In 1977, Ericsson launched the AXE switch, which elevated the status of Ericsson to one of the global leaders of telecommunication equipment industry. The AXE switches are easily adjustable to different regional landline telecommunication systems, and the cost is lower because of its innovative modular architecture. In 1989, Ericsson was ranked the fourth largest supplier of landline telephone switches with a 13% global market share (Ericsson 1989). AT&T (U.S.), Northern Telecom (Canada), and Alcatel (France) held larger market shares than Ericsson at the time; however, most of their sales were from the well-established domestic markets rather than the competitive international market.

In addition, Ericsson had been deeply involved in mobile cellular technology since the 1970s. During the commercial development of mobile cellular technologies in the 1980s, the flexible architecture of the AXE switch enabled Ericsson to cope successfully with various first generation cellular mobile telecommunication technical standards, such as Nordic Mobile Telephony (NMT), Advanced Mobile Phone System (AMPS), and Total Access Communication System (TACS). In 1989, Ericsson became the unrivaled leader in mobile telephony systems, holding 40% of the world market (Ericsson 1989).

In the 1990s, Ericsson led the advancement of telecommunication technologies, expanded its business, and maintained its dominant position in the rapidly expanding mobile infrastructure market. In 1999, Ericsson held the majority (27.6%) of the global mobile infrastructure market (Gartner 2001). In 2000, Ericsson was ranked the second largest telecommunication equipment provider with revenue of USD 29.26 billion, closely following Nortel (formerly Northern Telecom), which posted USD 29.80 billion in revenue.

[Figure 1 about here]

Huawei

Huawei was established in 1987 by Ren Zhengfei, a former People's Liberation Army (PLA) communications officer, and five fellow PLA members with a starting capital of Renminbi 20,000 (about 3,000 US dollars). Huawei started from scratch in the city of

Shenzhen (Xu and Girling 2004). The firm used to be a telecommunication equipment distributor with a barn on a Shenzhen farm as a office, from which the founders sold telephone switches imported from Hong Kong.

In 1990, Huawei decided to take the risk of transforming itself into a telecommunication equipment manufacturer by using in-house research and development, rather than joint ventures with multinational firms, which was the strategy of typical Chinese manufacturers. However, Huawei had neither telecommunication equipment knowledge nor sufficient money for such development. Huawei's five researchers experienced repeated failures and the company was forced to reinvest all its profits. However, by using reverse engineering on an imported switching device and networking equipment, Huawei developed the HJD48 (a 512-line analog telephone switch) in 1991. Huawei's cost advantage allowed it to gain access to the rural Chinese market, a market that was neglected by multinational firms.

Huawei expanded its efforts to develop a large capacity digital switch by recruiting engineers who had experience and knowledge of developing the HJD-04 system (the local Chinese digital switch) at Jurong (Great Dragon), a state-owned company. In 1993, Huawei achieved a breakthrough when it launched C&C08, a program-controlled public digital switch system (PDSS) with a switching capacity of 2,000 lines. Huawei started to deploy the C&C08 to the small cities and rural areas in which Huawei had built close customer relationships. In 1995, Huawei upgraded the C&C08 to accommodate 10,000 lines, and thereafter penetrated the major city market, which at that time was dominated by multinational firms and joint ventures. Huawei increased its market share rapidly by rolling out an aggressive marketing campaign and taking advantage of the Chinese government's support as exemplified by its "buy local" policy and preferential loans.[2] In 1998, Huawei became the largest digital switch supplier in China (Mu and Lee 2005).

From the mid-1990s, Huawei established domestic R&D centers in Beijing and Shanghai, through which it extended its R&D into access equipment, optical transmission, data networks, and wireless networks, thereby transforming itself into an end-to-end solution provider. Huawei expanded its product line to include High-Capacity Optical Networking and Enabling Technologies (HONET), integrated access network, and

[2] The Chinese government started to impose tariffs on imported telecommunications equipment, and extended Huawei CNY 3.9 billion in buyer's credit from China Construction Bank, and CNY 3.5 billion of revolving credit from the Bank of China and Industrial and Commercial Bank of China (ICBC).

synchronous digital hierarchy (SDH) optical transmission equipment in 1996, data communication equipment (routers) in 1997, and GSM mobile communication systems in 1998. However, the Chinese mobile communication market remained dominated by multinational firms; local Chinese firms, including Huawei, held less than 5% of the market share until 1999.

In 1996, Huawei began to reach out to the international market, starting from Hong Kong and extending to emerging and developing countries and regions, such as Russia, India, South Africa, and Latin America. Huawei's international market revenues were sluggish during the first few years, but surged from the late 1990s, reaching USD 120 million in 2000. Despite these changes, respective sales comprised less than 5% of its total.

To cope with the challenge of the increasing complexity and inefficiency as the result of the rapid growth of the business and organization (Figure 2), Huawei set up Huawei Basic Law and conducted business and R&D process reengineering from the mid-1990s. To achieve long-term sustainable growth, Huawei, with IBM's assistance, prepared an advanced management system, which incorporated integrated product development (IPD) and integrated supply chain (ISC) (Fan 2010).

With remarkable growth momentum, Huawei posted sales of USD 1.93 billion in 2000. Nonetheless, this equaled just one-fifteenth of Ericsson's sales.

[Figure 2 about here]

2.2 Huawei's Sales Exceeding Those of Ericsson

The telecommunication sector investment experienced a sharp decline with the bursting of the IT bubble in the early 2000s. OECD member countries cut their investment in telecommunication infrastructure by almost 40% over two years from USD 241 billion in 2000 to USD 150 billion in 2002 (Figure 3).

[Figure 3 about here]

Figure 4 shows the ripple effects of the severe downturn in the telecommunication equipment industry;[3] The downstream industry's drastic slowdown resulted in the decrease of the total sales of telecommunication equipment of major firms by more than 30% from 2000 to 2002 .[4] Nortel, Ericsson, and Lucent (formerly AT&T's telecommunication equipment branch), whose main business area was landline/mobile telecommunication infrastructure, lost more than half of their telecommunication equipment sales in the same period.[5]

[Figure 4 about here]

To address this slowdown, and survive, major firms in the market embarked on mergers and acquisitions from the mid-2000s to achieve economies of scale. Alcatel, a French firm with a 108-year history, and Lucent Technologies, a 137-year-old US firm, officially announced their merger in April 2006. The combined Alcatel-Lucent was established in December 2006. In June 2006, Nokia and Siemens agreed to launch a new joint venture by merging their telecom equipment arms and founding Nokia Siemens Networks (NSN) in April 2007. Moreover, Nortel, which had posted USD 29.80 billion in sales in 2000, the world's highest, filed for bankruptcy protection in January 2009, and sold its LTE and CDMA business divisions to NSN in June 2009. In 2011, Motorola was split into Motorola Solutions (the telecommunication infrastructure branch) and Motorola Mobility Holdings (mobile phones), with Motorola Mobility taken over by Google. Excluding Cisco, the main business of which is data communication equipment, and NEC, which had a large established domestic market, Ericsson was essentially the only survivor of the industry turmoil in the 2000s.

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[3] Telecommunication equipment includes landline/mobile telecommunication infrastructure (e.g., switching systems and base transceiver stations), user equipment (e.g., mobile phones) and enterprise network infrastructure (e.g., routers, hubs, and modems). The sales of these telecommunication equipment are analyzed. Sometimes, large sales of firms in the telecommunication equipment industry sometimes come from the purchase of equipment by other industries, such as consumer electronics, computers, and electronic components; thus, analyzing the firms' telecommunication equipment sales is more important than analyzing their total sales in determining the effects of the slowdown in the downstream industry.

[4] "Major firms" refers to the telecommunication equipment manufacturers that posted at least USD 10 billion sales in telecommunication equipment as of 2000. These are Nortel, Ericsson, Nokia, Lucent, Cisco, Motorola, Alcatel, Siemens, and NEC

[5] The figure fell further to 40%, if we exclude Nokia, whose mobile phone sales represent a high percentage of its total sales .Nokia showed a sales increase; however, it reflects Nokia's sales increase from the mobile phone market, not from the infrastructure market.

Figure 5 compares the annual sales of Huawei and Ericsson. Ericsson witnessed a drastic 40% drop in sales from 2000 to 2002.[6] From the mid-2000s, Ericsson's sales improved; it recouped its global telecommunication infrastructure investment, and has recently showed considerable growth. However, owing to its overwhelming sales growth, Huawei was able to overtake Ericsson finally in terms of annual sales in 2012.[7]

In the early 2000s, the Chinese telecommunications industry, particularly mobile telecommunication, continued to expand despite the global slowdown. Nevertheless, Huawei had limited success in the Chinese mobile telecommunication market. Although Huawei made significant strides in the GSM value-added service market (e.g., its short message center and mobile intelligent network), it was nowhere near breaking into the GSM core infrastructure market, which had been dominated by multinational firms, including Ericsson. In addition, Huawei missed the opportunity to participate in the new domestic CDMA market, forcing the Chinese firm to look to the international market. Fortunately, Huawei's R&D and its international market efforts in the late 1990s started to pay off from the early 2000s. In 2003, Huawei won the dual-band GSM network contract from MegaFon, the largest wireless operator in Russia, and Etisalat's UMTS network contract in the UAE, the first UMTS network project in the Middle East and the Arab world. Huawei also built the world's first automatically switched optical network (ASON) network for Telemar and Oi in Brazil. From the early 2000s, Huawei made inroads into the European market, and in 2001, it built optical transport networks for PfalzKom in Germany and Neuf in France.

[Figure 5 about here]

To push forward with its global expansion, Huawei undertook radical organizational restructuring in the mid-2000s. After failing to obtain the British Telecom supplier certification in 2003, Huawei commenced a series of painstaking reform, transforming its

[6] The main reason for Ericsson's sales drop in the early 2000s was the downturn in the telecommunication infrastructure industry; however, a portion of this decrease can be attributed to the spin-off of its mobile phone division. Ericsson spun off its mobile phone division in 2001 and conducted business through Sony Ericsson, a joint venture with Sony, since 2001. According to Ericsson's annual report, mobile phones accounted for 20.5% (SEK 56.3 million) of its total sales, and equipment systems (telecommunication infrastructure) accounted for 70.9% (SEK 194.1 million) in 2000. Sales for equipment systems declined by 4% to SEK 187.8 million in 2001, and declined by 30% to SEK 132.0 million in 2002.

[7] Unlike Ericsson, Huawei's mobile phone business is internal. In 2012, the mobile phone sales contributed 22% of Huawei's total sales.

hierarchical, functional structure into a multi-dimensional matrix structure (Fan 2010). Huawei became more flexible and more capable of responding swiftly to the global market demand. To finance its business expansion and to address the increasing cost-consciousness of customers, Huawei obtained credit lines in 2004 – USD 10 billion from China Development Bank and USD 600 million from Export-Import Bank of China. Huawei was further supported by Sinosure's export buyer's credit insurance.

In 2004, Huawei finally entered the first-tier international market – Europe's third-generation mobile network – when the Chinese company beat Ericsson to win the Telfort WCDMA contract in the Netherlands. Huawei products' cost-saving advantages, rather than their low cost, stood out for Telfort. Huawei's unique and innovative solution, a distributed base station system, allowed Telfort to upgrade its existing base stations with WCDMA technologies instead of building new ones (Fan 2010). With Huawei, Telfort could not only save one-third of the total cost of ownership (TCO) for the network but also sidestep the environmental issues that had impeded its rapid deployment. In 2005, Huawei was selected as one of the priority suppliers of British Telecom for its 21st Century Network program. With its successful entry into the first-tier market, Huawei's 2005 overseas revenues exceeded its Chinese market revenue for the first time. In the following year, Huawei was awarded the largest GSM network contract in the Southern Hemisphere by Brazil's Vivo, and a WCDMA network contract by the world's largest mobile operator, Vodafone. Huawei also entered the United States and Japanese markets. In 2007, Huawei ranked eighth on the list of the top 10 telecommunication equipment manufacturers for the first time.

With consistent innovation, Huawei dominated fourth-generation mobile technology and delivered one of the world's first LTE networks for TeliaSonera of Norway in 2009. Huawei emerged as the world's second-largest provider of telecommunication infrastructure from 2009, rapidly narrowing the gap with the global leader, Ericsson. Huawei ultimately topped Ericsson in terms of annual revenue in 2012, and in 2013 increased its revenue leadership, achieving USD 39.36 billion in revenue, which was higher than Ericsson's USD 35.39 billion.

3. Data, Methodology, and Hypotheses

3.1 Patent Data and Making Sense of Comparison

Indicators based on R&D expenditures, patent statistics, and new product introductions, or a combination of these indicators, among others, have been widely used to measure firm's technological capabilities (Schoenecker and Swanson 2002). Given that patents and patent citations provide detailed information on the inventions and cover a relatively long period as well as virtually all fields of technology (Griliches 1990), they have been accepted as a reliable, though not perfect, source of information to measure firms' technological capabilities (Narin et al. 1987; Patel and Pavitt 1997). Thus, we analyzed the patents and related citations of Huawei and Ericsson (European patents from 2000 to 2010).

The results of patent analysis may vary greatly depending on the data employed. Hence, we built an appropriate patent data set. First, patents filed by Huawei and Ericsson with various national authorities were obtained from the PATSTAT database, which was created by the European Patent Office (EPO). The total number of patents from 2000 to 2010 show that both firms filed the majority of their patents with three common national authorities, namely, EPO, the United States Patent and Trademark Office (USPTO), and the Chinese State Intellectual Property Office (SIPO). These national authorities report patent statistics to the PATSTAT database (Table 1). Huawei filed the most patents with SIPO, followed by EPO and USPTO, whereas Ericsson filed the highest number with EPO, followed by USPTO and SIPO.

[Table 1 about here]

Huawei exceeded Ericsson in terms of the number of patents filed at all three patent offices: SIPO in 2001, USPTO in 2007, and EPO in 2008. The results provide strong evidence that Huawei's technological catch-up with Ericsson is real and not a spurious result from biased patent data. However, Huawei's technological strength could be overestimated based on Chinese patents owing to its home country advantage and underestimated in terms of US patents because of its low business presence in the North American market.[8] Thus, European patents were used, rather than Chinese or US patents,

[8] In 2009, Huawei's sales in the North American market was USD 408 million, which is less than 2% of Huawei's total sales (BusinessWeek.com 2010).

for further analysis to ensure objectivity of the analysis of the two firms' technological strength.

Establishing that these two companies are similar enough to be compared is necessary; that is, confirming that Huawei and Ericsson compete in similar technological areas is vital. Otherwise, the comparison would not make any sense (Joo and Lee 2010). This essential prerequisite process can be conducted by comparing the technological characteristics of the two companies. Given that the level of competition between the two firms tends to increase when they rely on increasingly similar sets of technology (Podolny et al. 1996), the level of technological similarity of the two firms' patent portfolio was analyzed using the measures of technological proximity (Jaffe 1986).

The technological proximity between two firms, *i* and *j*, is defined as follows:

$$Technological\ Proximity_{ij} = \frac{\sum_{t=1}^{T} P_{it}P_{jt}}{\sqrt{\sum_{t=1}^{T} P_{it}^2}\sqrt{\sum_{t=1}^{T} P_{jt}^2}} \ ,$$

P_{it}: the share of firm *i*'s patents in the technological field *t* among the total patents of firm *i*

T: total number of technological fields.

Technological proximity takes a value between 0 and 1. The more similar the two firms are in their technological specialization, the higher the value that proximity takes. Huawei and Ericsson's technological proximity at the International Patent Classification subclass level stands at 0.912. This value is high and suggests that the two firms compete fiercely in similar technological fields. The average technological proximities among US manufacturing firms within the same sector is 0.75 (Jaffe, 1989), and the technological proximity between Samsung and Sony, two major competitors in the global electronics industry, is 0.98 (Joo and Lee 2010). Thus, we can say that comparing these two companies is sensible given the high degree of technological proximity of the two companies

3.2 Main Hypotheses and Measurement

The patents and related citations of Huawei and Ericsson were analyzed to investigate whether a latecomer catches up with forerunners by developing similar or different technologies compared with those by the forerunners. Similar technologies imply that the latecomer simply attempts to imitate the incumbents, whereas different technologies refer

to the latecomer seeking to create new technologies and take a different technological path or trajectory from those of the incumbents. The main hypothesis of this study is that Huawei has caught up with Ericsson in terms of market shares by developing different technologies.

This contrast between the similar versus different technologies can be discussed using the literature on technological catch-up. Early literature (Lall 2000; Kim 1980; Westphal, Kim, and Dahlman 1985; Hobday 1995) has observed that the latecomer tends to catch up with the advanced countries by assimilating and adapting the latter's obsolete technology. This is consistent with product life cycle theory (Vernon 1966). However, an emerging view (Lee and Lim 2001; Lee 2013) points out that the latecomer does not simply follow the advanced countries' path of technological development but sometimes skip certain stages or even create their own path that is different from those of the forerunners. This observation is consistent with the idea of leapfrogging (Perez and Soete 1988); some latecomers may be able to leapfrog older vintages of technology, bypass heavy investments in previous technological systems or stages, and make preemptive investments in emerging technologies to catch up with advanced countries in new markets.

Several studies have confirmed leapfrogging or path-creating through case studies in East Asia (Lee et al. 2005; Mu and Lee 2005). However, studies that have quantitatively analyzed whether laggards successfully catch up with forerunners based on the same or different technologies are rare. Similarly, studies that have suggested a method to assess whether the technological path of the laggard is the same or different from the forerunners have not been found.

In this study, four criteria were used to assess the same or different technologies. First, the quality of the two firms' patents, which is measured by the average number of received citations, was examined to determine if the latecomer's patent quality catches up with or even surpasses that of the forerunner. Second, the mutual citations between the two rival firms' patents were examined to establish the extent through which they rely on each other as their source of knowledge. For instance, if Huawei's patents cite many Ericsson patents, then Huawei is imitating and relying on Ericsson. Third, we address the question of whether two firms rely on the same sets of knowledge from the third party firms in their invention activities by measuring the 'indirect dependence' between two firms using the common citation rations suggested by Mowery et al. (1998). This common citation rate

measures the similarity of two firms' knowledge sourcing (or impacts) at a more micro level. Fourth, the two rival firms' degree of self-citation, which can measure their self-reliance on their own knowledge base, was examined (Lee 2013; Ch. 5). This study focuses on the latecomer's degree of self-citation to assess the extent to which it becomes independent of external knowledge sources and self-reliant on its own knowledge base.

The catching-up process has a dynamic nature. Hence, this study's grand hypothesis is that the latecomer firm would try to imitate the forerunner by incorporating the same or similar technologies in its early stages but would try to create new or different technologies from the forerunner firm to be successful. The logic behind this idea is simple. If a latecomer continues to follow the same path as its forerunner, the latecomer would always remain behind the forerunning company, unless it runs much faster than its target, which is not easy. Thus, an alternative for a latecomer is to explore a short-cut or a different path. Lee (2013: xxi) has observed that "just trying to emulate or replicate the practices of the forerunning economies is not enough, and catch-up realizes only if you take a different path."

The present study also investigates whether Huawei relies more on recent or old technologies than the incumbents by examining the latter's citation lags, and whether the former relies more on scientific knowledge than the latter in terms of their patents' citation in scientific literature. These two aspects are verified by an analysis using a large sample of firms in Park and Lee (2015), and this study does a similar job for the case of these two comparable firms. A possible hypothesis is that the latecomer would rely more on scientific literature when catching-up because science literature is not protected by any IPR forms and is freely available for use. Thus, the latecomer has a reason to explore fully useful knowledge from scientific commons in their catch-up efforts.

The latecomer may try to rely less on old technologies protected by patents, which indicates continued reliance on the incumbents. Such attitude is also desirable to avoid any possible patent dispute with the incumbents. Thus, the latecomers have a reason to explore a technological trajectory that is less connected to existing technologies. Thus, their citation pattern will be geared more toward recent patents. The average cycle time of their patent portfolio would be shorter than those of the incumbents. This hypothesis is interesting given that some studies (Park and Lee 2006; Lee 2013) have found that the latecomer countries tend to specialize in short-cycle technology based sectors. These studies are

concerned with across-sector specialization, whereas the present study explores a twisted question of whether a latecomer firm's patent portfolio would show the shorter average cycle time than those of the incumbents in the same sector.

4. Catching-up with Similar or Different Technologies

4.1 Is Huawei's Technology of Higher Quality than that of Ericsson?

Not all patents are equal. The distribution of patent quality, technological impact, and the economic value is highly skewed. Few high quality patents are available, and most patents have low quality. Therefore, quality not quantity counts.

The quality of two firms' patents can be measured by the average number of citations received; the more citations a patent receives, the higher the consideration that it is valuable or worthy of use (Albert et al. 1991; Hall et al. 2005). Figure 6 offers a comparison of the average number of citations that the two firms' patents received. Figure 6(a) considers the citations from all patents in the PATSTAT database and includes citations from US patents. The number of citations received by EPO patents is included in Figure 6(b).

Figure 6 indicates that Huawei has remained ahead of Ericsson in terms of the average number of citations received since the early 2000s. Huawei filed its first European patents in 2000. It has outclassed Ericsson in terms of patent quality from the beginning and remained in the lead ever since.

[Figure 6 about here]

This phenomenon may be partly attributed to the differences in patent strategies of Huawei and Ericsson, especially in the early 2000s. Huawei may have filed EPO patents for only a few of its high-quality inventions because Europe was not its home market and the cost of an EPO patent application was far greater than the cost of a Chinese patent application. By contrast, Ericsson may have filed EPO patents for most of its inventions because the European market was its home market.[9] Ericsson's patent strategy, which is filing a few good-quality patents and many low-quality patents, may have resulted in Ericsson's low average patent quality.

[9] Table 1 shows that Ericsson filed EPO patents for most of its inventions, whereas Huawei filed EPO patents for only a few of its inventions in the early 2000s.

Notwithstanding the difference in the two firms' patent strategies, the result of his study provides strong evidence that Huawei caught up with Ericsson in terms of patent quality no later than the mid-2000s. Huawei filed a comparable number of EPO patents as Ericsson from the mid-2000s but stayed ahead of Ericsson with respect to patent quality. Thus, Huawei filed as many quality EPO patents as Ericsson did.

Catching up with patent quality than patent quantity is more difficult for a latecomer. When a latecomer focuses on the practical implementation of an intellectual foundation laid down by its forerunners, the latecomer may be more successful in generating a large number of patents applications. However, doing so may restrain the latecomer from catching up with the quality of patents because the latecomer's developments would reinforce the economic and technological value of the basic principles invented by the forerunners. Thus, the catch-up in patent quality requires a latecomer to produce somewhat radical innovations, which is exactly what Huawei did.

The catch-up of patent quality can be achieved by taking a different technological path than the one taken by the forerunners or by taking the same path. Achieving both is rare because the two paths require a latecomer to adopt different and contradicting strategies and capabilities. If a latecomer tries to climb the same technological ladder after the forerunning incumbents, most of the important and valuable inventions on the current and higher steps are frequently preempted by the forerunners, which leaves the latecomer minimal chance. Thus, taking a bypass or a different technological ladder may allow a latecomer to circumvent such difficulties in catching up with patent quality. However, this would be a highly challenging and risky undertaking. In the former case, a latecomer often takes exploitative innovation strategy by carefully selecting existing state-of-the-art technologies and focusing on refining and optimizing them to enhance efficiency. In the latter case, the latecomer needs to assume an explorative innovation strategy by deliberately taking the risk of uncertainties and searching wide sets of knowledge sources to discover a new breed of ideas (March 1991).

Developing similar or different technologies to the forerunning incumbents must have been an important decision for Huawei. Huawei's patent quality catch-up shows that the company made a conscious decision at some point although what exactly this decision was is unclear.

4.2 Does Huawei keep Imitating Ericsson? Mutual Citations

Latecomers usually start the technological catch-up by acquiring and assimilating forerunners' knowledge; subsequently, they make improvements or sometimes take innovations (Kim 1980). Latecomers are unlikely to sever their reliance on the forerunners' knowledge given that they do not have their own innovations. Hence, the latecomer's break from the forerunners' knowledge can be a good signal because such break signifies that the latecomer has its own innovations. The level of technological dependence between the catching-up firm and the leading firm can be analyzed by the degree of mutual citations (Joo and Lee 2010).

The technological dependence of firm *i* on firm *j* is defined as follows:

$$\text{Technological Dependence}_{ij} = \frac{Firm\ i's\ citations\ directed\ to\ Firm\ j's\ patents}{Total\ citations\ in\ Firm\ i's\ patents}.$$

Figure 7 shows that Huawei is becoming less dependent on Ericsson.[10] However, negligible citations by Ericsson have been found on the patents of Huawei. Given Huawei's catch-up in patent quality, Ericsson might have been increasingly dependent on Huawei's technology. However, Ericsson's technological reliance on Huawei has remained unchanged. The results corroborate the argument that Huawei has taken a different path from Ericsson.

[Figure 7 about here]

4.3 Is Huawei having the same knowledge sourcing and impacts as the Ericsson?

While mutual citations can measure the 'direct dependence' between the two firms, we can also think of the 'indirect dependence' between two firms by addressing the question of whether two firms rely on the knowledge from the same sets of the third party firms in their invention activities. This idea of common citations between two firms is called the degree

[10] Huawei also cited the patents of other forerunners (Nokia, Lucent, Nortel, Alcatel, and Siemens). Huawei's technological dependence on the other forerunners also showed a generally decreasing trend.

of technological overlap between the two firms, which was suggested by Mowery et al. (1998). This common citation rate measures the similarity of two firms' knowledge sourcing (or impacts) at a more micro level. This index measures the degree to which two firms' technologies are based on (citing) the same patents (knowledge sourcing aspect), or the degree that two firms patents are used (cited) by the same patents (knowledge impact aspect).

The common citation rate (A) between two firms, *i* and *j*, in terms of the common knowledge sourcing aspect is defined as follows:

$$Common\ Citation\ Rate\ (A)_{ij} = \frac{Citations\ by\ firm\ i's\ patents\ to\ the\ patents\ \ also\ cited\ by\ \ firm\ j's\ patents}{Total\ citations\ made\ by\ \ firm\ i's\ patents} + \frac{Citations\ by\ \ firm\ j's\ patents\ to\ the\ patents\ also\ cited\ by\ \ firm\ i's\ patents}{Total\ citations\ made\ by\ \ firm\ j's\ patents}.$$

By using the citations made by two firms, the index (A) measures the degree that both firms rely on the common pool of knowledge held by the third party firms. It is defined as, among each firm's total citations made, the share of citations made to the third party patents which are commonly cited by both firms' patents. The index takes a value between 0 and 1. The more similar the two firms are in their knowledge sourcing from other firms, the higher the value it takes.

The common citation rate (B) between two firms, *i* and *j*, in terms of the common impacts/applications aspect is defined as follows:

$$Common\ Citation\ Rate\ (B)_{ij} = \frac{Citations\ to\ firm\ i's\ patents\ made\ by\ the\ patents\ \ also\ citing\ \ firm\ j's\ patents}{Total\ citations\ made\ to\ firm\ i's\ patents} + \frac{Citations\ to\ firm\ j's\ patents\ made\ \ by\ \ the\ patents\ also\ citing\ firm\ i's\ patents}{Total\ citations\ made\ to\ \ firm\ j's\ patents}.$$

By using the citations received by two firms, the index (B) measures the degree that both firms have impacts on the same set of the third party firms. It is defined as, among each firm's total citations received, the share of citations received by the patents which cite both firms' patents. The index takes a value between 0 and 1. The more similar the two firms are in their impacts on other firms, the higher the value it takes.

As shown in Figure 8, the common citation index (A) measuring the degree of the overlaps by two firms in their knowledge sourcing is 0.045, whereas the common citation

index (B) measuring the degree of the overlaps by two firms in their knowledge impacts is 0.026. This level of common citation rate is close to the average.[11] It is very low, compared to the common citation rate between Samsung and Sony which is as high as 0.39 (citation made) and 0.32 (citation received) (Joo and Lee 2010), This implies that Huawei and Ericsson may not share the same knowledge sources, and their knowledge have had impact on different types of the firms or innovations.

[Figure 8 about here]

4.4 Is Huawei getting Independent? Self-citations

A firm's ability to create new knowledge from its own knowledge base is an important aspect of its technological capability. Firms attempt to utilize their internal knowledge base before relying on external sources because establishing in-house proprietary technologies is crucial to their technological competitiveness. The degree to which a firm is capable of drawing innovation from its own knowledge base can be measured by the ratio of self-citations (i.e., citations directed to its own patents) of the firm's patents.[12] The higher a firm's technological capabilities are, the higher a self-citation ratio that it will show (Lee 2013: Ch. 5).

In the meantime, if a latecomer follows a technological path with an industry-wide acceptance, it may become less dependent on each major forerunner's knowledge and become increasingly dependent on external knowledge sources by diversifying its knowledge sources. Hence, a latecomer's reduced technological reliance on each major forerunner does not directly imply that the latecomer has taken a bypass or a different technological ladder from the forerunners. Therefore, this reduced reliance needs to be further analyzed. Specifically, whether the latecomer has become less dependent on external knowledge sources as a whole or whether the latecomer has become more self-reliant on its own knowledge base should be investigated.

Figure 9 shows that Huawei's self-citation ratio has been steadily increasing and

[11] The average common citation rate between two firms randomly selected is between 0.01464 and 0.02413 (Mowery et al. 1998). The average common citation rate between pharmaceutical and biotechnology firms in in-vivo human therapeutics, which is a narrow area, is 0.0254 (Rothaermel and Boeker 2008).

[12] The self-citation ratio also reflects a firm's technological capabilities (Lee 2013: Ch. 5). The increasing self-citation ratio of Huawei in Figure 9 can also be interpreted as Huawei's successful accumulation of technological capabilities.

eventually approaches that of Ericsson by the late 2000s. Thus, Huawei has become as self-reliant as Ericsson by increasingly developing technologies that are different from those of other firms, including Ericsson. The results support this study's argument that Huawei has been taking a different path from Ericsson.

[Figure 9 about here]

5. Catching-up with More Recent and Scientific Knowledge?

5.1 Huawei's Scientific Explorations (citations in non-patent literature)

When a latecomer firm follows the technological ladder used by its forerunners, it tend to narrows its search space to locate the state-of-the-art technologies on which it can improve. However, a latecomer who takes a different technological ladder from its forerunners needs to challenge conventional dogma to create a *de novo* pathway. Given that the knowledge within or surrounding conventional dogma does not promote the questioning of conventions, the latecomer expands its search space widely to formulate unprecedented ideas and searches into a genuine principle. Therefore, a latecomer is more likely to conceive ideas from basic research when it takes a different path.

The extent to which a firm draws ideas from basic research can be investigated by the number of citations directed to non-patent literature, most of which comprises scientific articles in academic journals. Such extent reflects the proximity to basic research. The more ideas are taken from basic research, the more non-patent literature is cited.

Figure 10 provides the average number of citations directed to non-patent literature by the patents of Huawei and Ericsson. Huawei's patents had cited more non-patent literature than Ericsson's patents until recently. The result suggests that Huawei has been actively exploring basic research,[13] which confirms this study's claim that Huawei has been catching up by developing different technologies.

[Figure 10 about here]

[13] Exploring basic research is not an easy task, especially for a latecomer. Huawei may have been reaping the benefits of China's strong capabilities in basic research.

5.2 Does Huawei relies on More Recent Technologies: Citation Lags

Backward citation lag (BWL) measures how recent are the prior patents that a patent cites, whereas forward citation lag (FWL) indicates how quickly a patent is cited by subsequent patents. The two indicators show how agile a firm is in assimilating new technologies to recreate them and how rapidly a firm's technologies are adopted for subsequent developments in the process of a technological catch-up.

BWL and FWL of patent *i* are defined as follows:

$$BWL_i = \frac{\sum_{j=1}^{NCITING_i} BLAG_j}{NCITING_i},\ FWL_i = \frac{\sum_{k=1}^{NCITED_i} FLAG_k}{NCITED_i},$$

$NCITING_i$: total number of citations made by patent *i*

$BLAG_j$: difference in the filing date between citing patent *i* and cited patent *j*

$NCITED_i$: total number of citations received by patent *i*

$FLAG_k$: difference in the filing date between cited patent *i* and citing patent *k*.

Huawei has shown shorter backward and forward citation lags, compared with Ericsson until recently. The results indicate that Huawei has focused on developing its technologies relying on more recent knowledge, which is consistent with the finding of Park and Lee (2015) with a bigger sample size. But it is a bit different but can also be considered together the finding by Park and Lee (2006) that the catch-up is more likely to take place in technological sectors with shorter technology cycles. A shorter backward citation lag shows that Huawei has been narrowing the technology gap with Ericsson by accelerating its technological progress with an up-to-date knowledge base. The shorter forward citation lag shows that Huawei's patents have had more immediate impact.

[Figure 11 about here]

6. Summary and Concluding Remarks

The present study has raised the question of whether a latecomer firm catches up with a forerunning firm in market shares by using technologies that are similar or different from those of the forerunners. The study has investigated the patents by Huawei and Ericsson and found that Huawei relied on Ericsson as a knowledge source in its early days but

subsequently reduced this reliance and increased its self-citation ratio to become more independent. The results of mutual citations (direct dependence), common citations (indirect reliance), and self-citations provide strong evidence that Huawei has caught up with or overtook Ericsson by taking a different path. Moreover, compared with Ericsson, Huawei developed its technologies by relying on more recent and scientific knowledge, and other firms in the industry have utilized its technologies more quickly. The results of citations to non-patent literature and citation lags showed that Huawei has conducted extensive exploration of basic research and maintained up-to-date technologies to accomplish its technological catch-up. Overall, this study suggests that exploring a new and different technological path from that of forerunners is a possible and viable catch-up strategy for a latecomer.

Moreover, Huawei's case re-confirms the hypothesis that a catch-up in technological capabilities tends to precede a catch-up in market shares, which was verified in the Samsung vs. Sony case on consumer electronics by Joo and Lee (2010). Huawei overtook Ericsson in terms of both quantity and quality of patent before it did in terms of annual sales. In sum, the results suggest that Huawei's catch-up with Ericsson in the telecommunication equipment market is not merely owing to its cost advantage, the large domestic market, or the Chinese government's support, but more importantly to its technological strength and independence.

The present study contributes to the literature on innovation and catch-up studies in several ways. First, it is one of the first studies that used a quantitative method to assess whether a latecomer is taking the same or different technological path that its forerunners have taken. The lack of a proper yardstick has often impeded in-depth catch-up research. This study's method can be applied to other catch-up cases. Second, the study provides quantitative evidence that supports the assertion that a latecomer catches up with the forerunner and finally forges ahead by taking a different technological path from the forerunner. The argument should be further investigated using more cases before it can be applied generally. However, this study casts serious doubt on the idea that a latecomer can catch up simply by following the same technological path as the forerunner. Third, this study finds that some successful latecomer firms utilize the basic research and up-to-date technologies more than the forerunning firm, which is contrary to the conventional impression. This idea, which also needs further investigation, suggests that a successful

catching-up may happen quite differently from the expected. Strongly generalizable conclusions cannot be made based on a single case; however, this study has shed a new light on the process of latecomer's innovation and catch-up.

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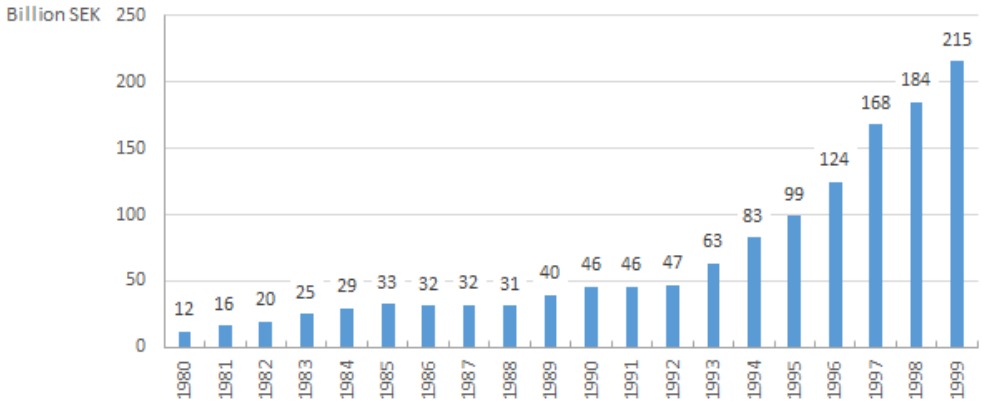
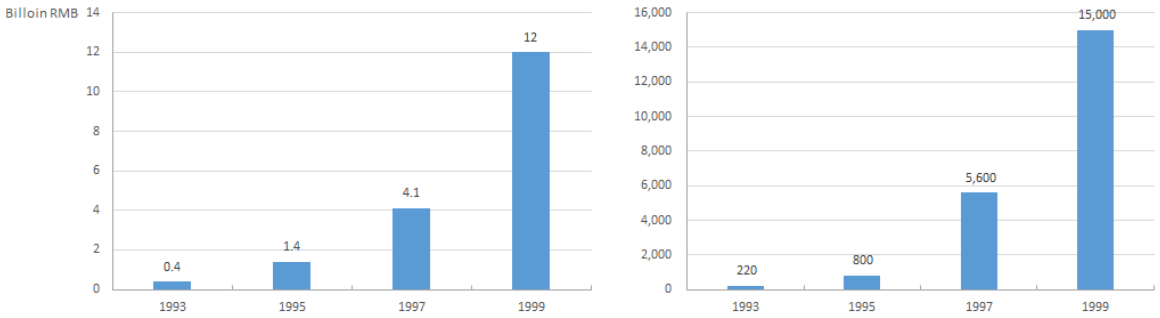
Figure 1. Ericsson's Revenue Growth in the 1980s and 1990s



Source: Ericsson's Annual Report from 1980 to 1999

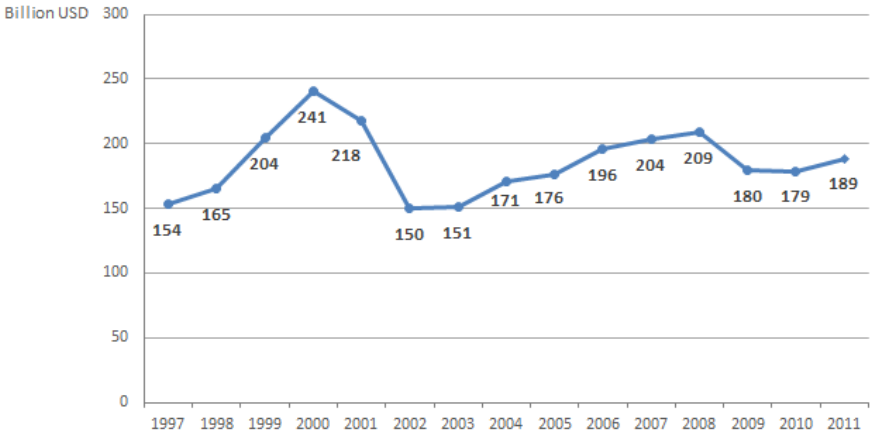
Figure 2. Huawei's Growth in the 1990s



(a) Revenue (b) Number of Employees

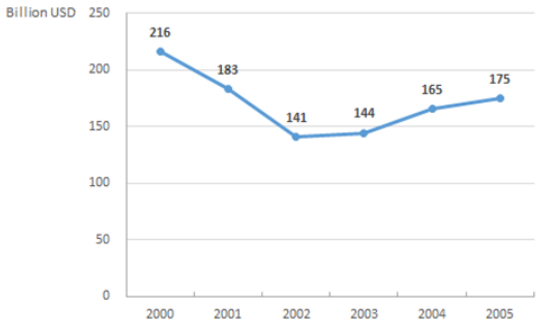
Source: Yu et al. (2004)

Figure 3. Telecommunication Infrastructure Investment of OECD Countries

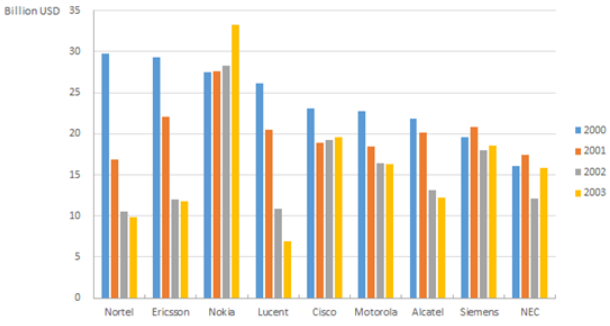


Source: OECD (2013), OECD Communications Outlook

Figure 4. Telecommunication Equipment Sales of Major Firms in the Early 2000s



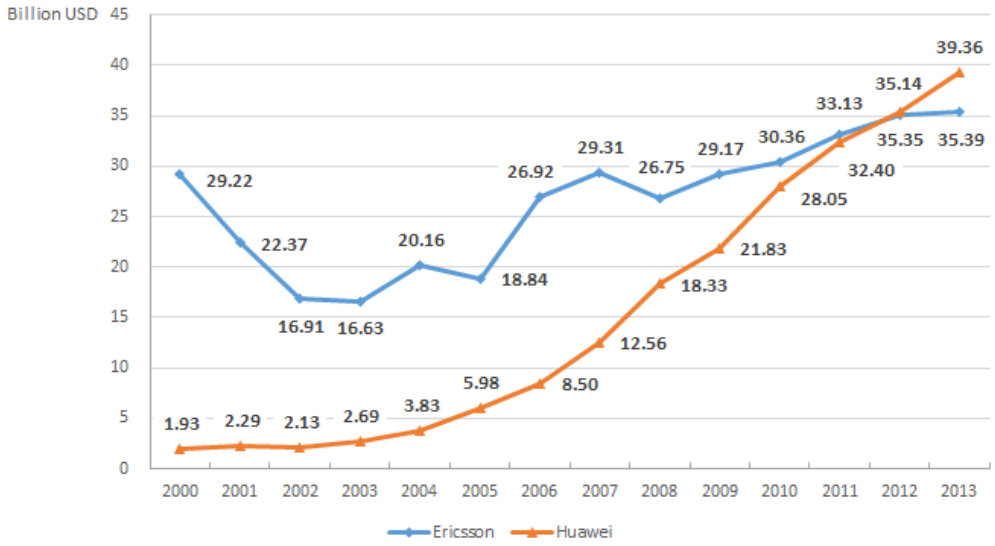
(a) Telecommunication equipment sales of all major firms



(b) Major firms' telecommunication equipment sales

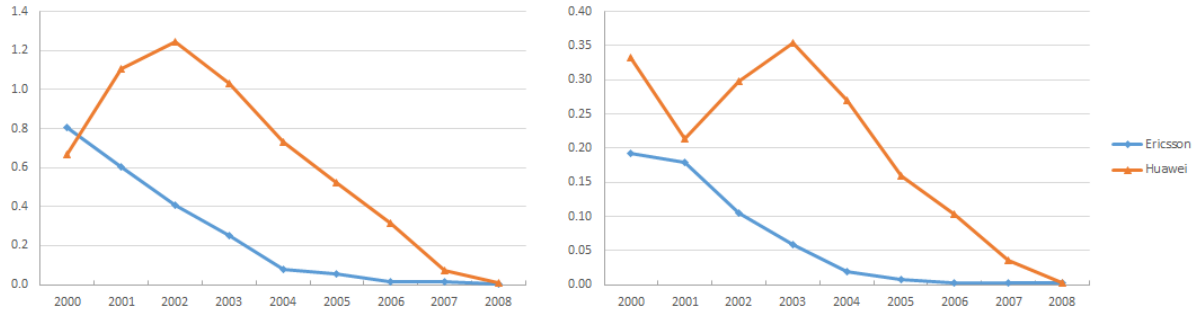
Source: Gartner (2005, 2006, 2007, 2010)

Figure 5. Annual Sales of Ericsson and Huawei



Note: Ericsson's annual sales are obtained from the Compustat Global Database. Huawei's annual sales are from Huawei's annual reports (Huawei, 2004, 2006, 2007, 2008, 2011, 2012). Huawei's annual sales for 2009 and 2010, which are reported in terms of Chinese yuan, are translated into US dollars using the closing exchange rate on December 31 of each year.

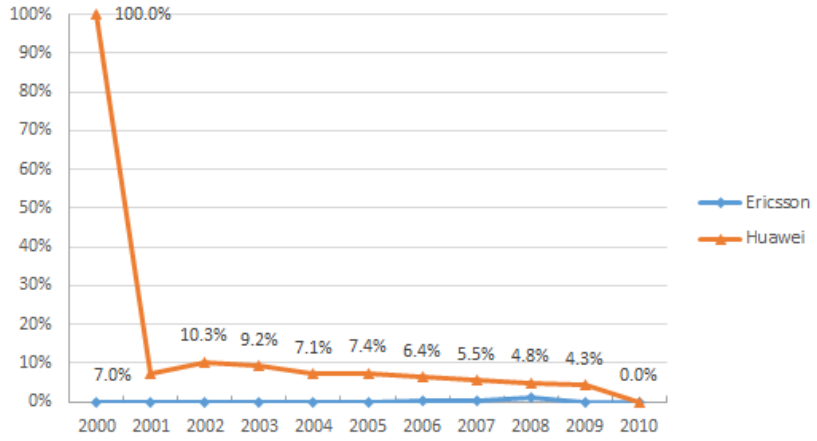
Figure 6. Average Number of Citations Received by Huawei's and Ericsson's Patents



(a) All citations in PATSTAT (b) EPO citations only

Source: Authors' estimations

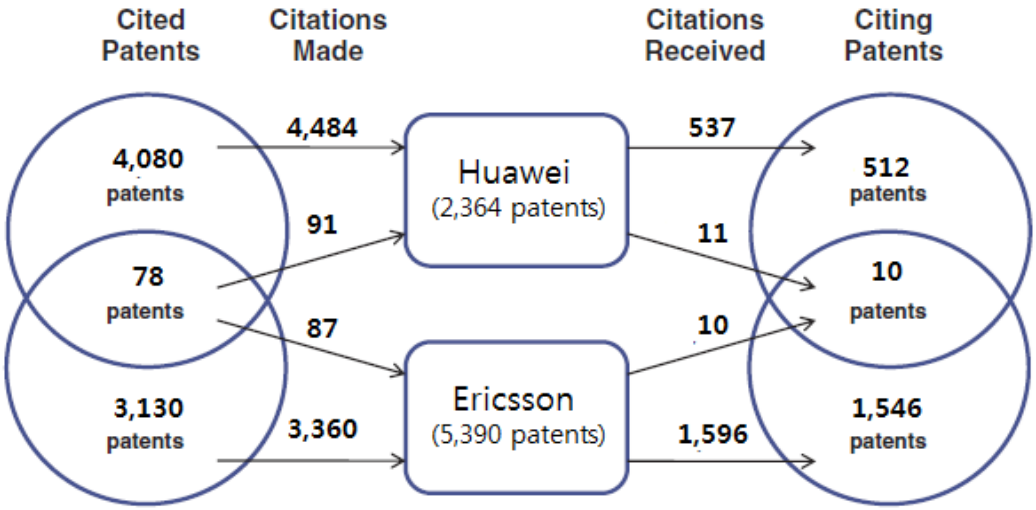
Figure 7. Share of Citations Directed to the Counterpart Firm's Patents



Source: Authors' estimation.

Note: We takes account of citations made to patents in PATSTAT and not EPO patents only.

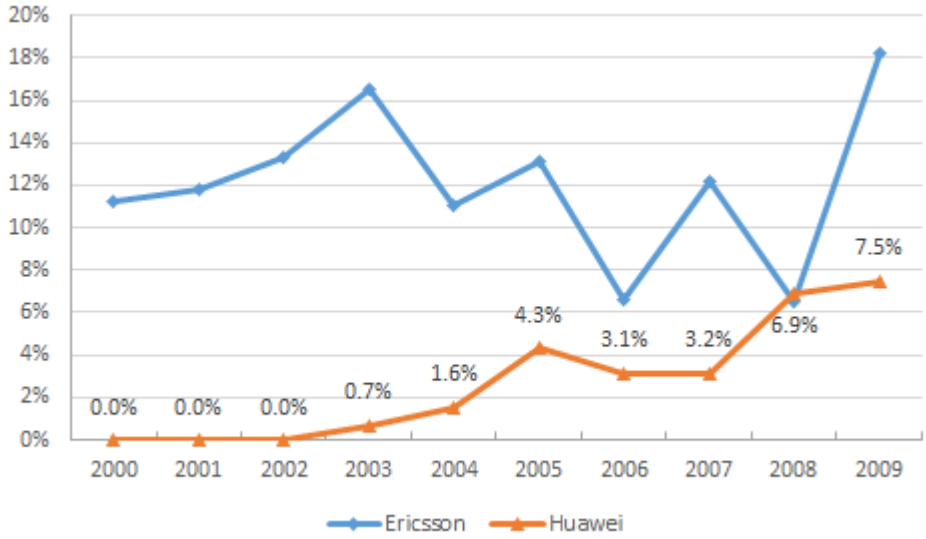
Figure 8. Technological Overlap between Huawei and Ericsson



Source: The authors

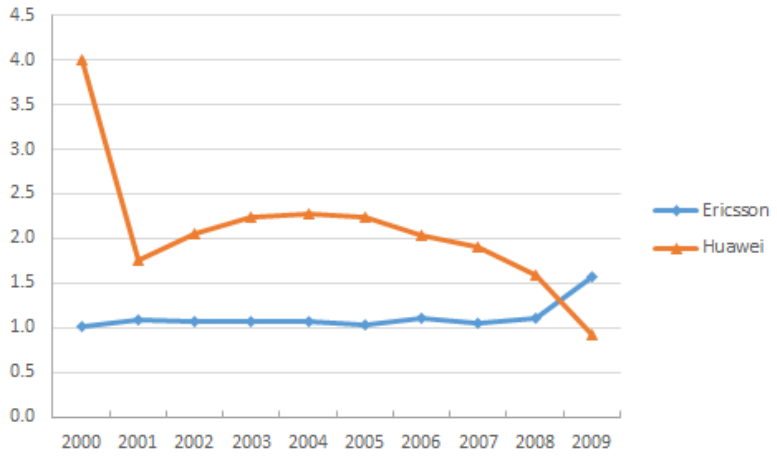
Notes: The common citation rate calculations use all citations in PASTAT, which includes citations from and to EPO patents and patents registered at other patent authorities

Figure 9. Self-Citation Ratio of Huawei and Ericsson



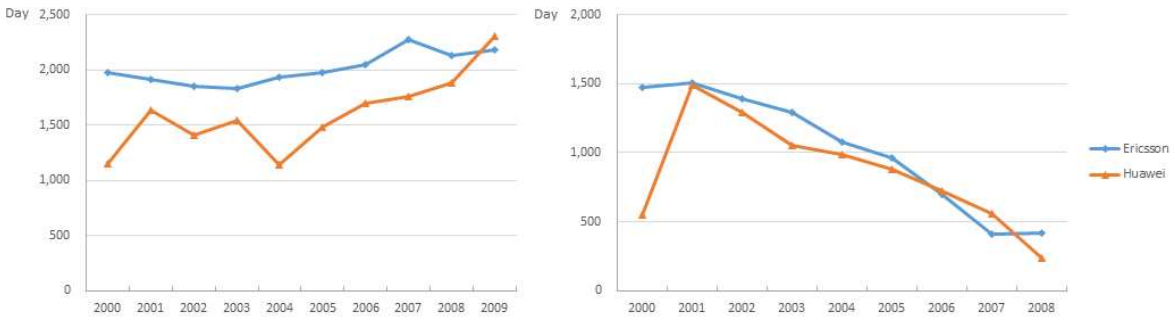
Note: Using citations made to patents in PATSTAT and not EPO patents only.

Figure 10. Average Number of Citations to Non-Patent Literature



Note: Using citations made to patents in PATSTAT and not EPO patents only.

Figure 11. Backward and Forward Citation Lag



(a) Backward Citation Lag (b) Forward Citation Lag

Note: Using citations made to patents in PATSTAT and not EPO patents only.

Table 1. Patent Filings of Huawei and Ericsson to EPO, USPTO, and SIPO

	Patent Office	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Huawei	EPO	3	28	37	62	85	219	563	647	627	90	3	2,364
	USPTO	1	4	12	54	56	96	226	314	448	528	75	1,814
	SIPO	181	452	1,004	1,480	2,098	3,484	5,668	4,523	3,402	666	n.a.	22,958
Ericsson	EP	871	766	606	431	521	523	618	658	378	16	2	5,390
	USPTO	890	616	272	333	489	406	231	288	230	95	7	3,857
	SIPO	601	193	248	254	353	379	443	299	91	n.a.	n.a.	2,861

Source: Authors' calculation based on the PATSTAT Database 2010 September Edition