GLOBAL VALUE CHAINS AND THE INNOVATION OF THE CHINESE MOBILE PHONE INDUSTRY

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EAI Working Paper No. 168

ISSN 0219-1318
ISBN 978-981-14-4975-8

Date of Publication: 10 February 2020

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Abstract

Global value chains (GVC) provide a new channel of innovation for firms participating in value chains or utilising the value chain strategy to grow. Upgrading to high value added segments of GVCs step by step is a linear model of innovation. Our analysis of Chinese firms involved in the value chain of the iPhone shows that the Chinese mobile industry has climbed up the ladder of the iPhone value chain and performed relatively sophisticated tasks beyond simple assembling works. In addition, by examining foreign value added and technology embedded in the smartphones of OPPO, Xiaomi and Huawei, I argue the Chinese smartphone vendors primarily follow a non-linear model of innovation, jumping directly to brand development before acquiring sufficient technology capacity. They have focused on incremental innovations and product differentiation by taking advantage of available technology platforms. The value chain strategy enabled them to effectively overcome technology deficiency and take a short-cut to catch-up with foreign rivals and evolve into leading smartphone makers in both domestic and foreign markets.

Key words: GVC, Innovation, mobile phone, China

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Introduction

Innovation and new technology are primary driving forces of economic development. Constant innovation is indispensable for a developing country that wishes to avoid the middle-income trap, grow into a high-income country and eventually become an industrialised economy. After the rapid economic growth of the last four decades, China now has a $13 trillion economy, second in size only to the United States'. Its GPD (gross domestic product) per capita is now more than $9,000, almost 10 times that when China started its revolutionary economic reform in 1979. Continuous technology innovation contributed substantially to that economic miracle. The Global Innovation Index 2018, compiled by Cornell University, INSEAD and the World Intellectual Property Organisation (2018) ranked China as one of the 20 most innovative economies in the world. China's aggregate investment in research and development (R&D) rose steadily in tandem with its growing economy. In 2017, Chinese R&D was equivalent to 2.13% of its GDP, making China the second in the world in R&D investment (Atkinson and Foote, 2019). Several studies (e.g. Wu, 2010; Lida, Shoji and Yoneyama, 2018) conclude that China's R&D investment contributed substantially to the growth of the total factor productivity of its economy.

To date, China is not only the largest exporter of labour intensive goods, such as shoes, clothes and toys, but also the largest exporter of personal computers, mobile phones, digital cameras and other information communication technology (ICT) products. The Chinese manufacturing output exceeded that of the United States to become the world's No. 1 (West and Lansang, 2018). In the world market for white goods, China's Haier Group has emerged as a leading maker of electronic appliances to the point that Haier is now recognised as a global brand. In the global market for personal computers (PCs), Chinese company Lenovo has surpassed HP and Dell to rank No. 1 with a 24% of the global market (IDC, 2018). In the global mobile phone market, home-grown Chinese brands Huawei, OPPO and Xiaomi are now three of the top five global smartphone brands (Counterpoint, 2019b). These achievements are largely the result of Chinese firms' constant endeavours to innovate.

There are many channels in which Chinese firms can innovate to strengthen their competitiveness in global markets and narrow technological gaps with foreign multinational enterprises (MNE) currently taking the lead in both technology and brand. R&D investment, foreign direct investment, innovation institutions, fiscal subsidies, learning by doing and reverse engineering are all effective tools for innovation and product enhancement. In this paper, I focus on the role of global value chains (GVCs) in facilitating both product and process innovation of Chinese firms.

With the unprecedented trade liberalisation and modularisation of the processes for production of manufactured products, in particular ICT, MNEs have reorganised their production along GVCs where specific activities and production tasks are standardised and allocated to firms in dispersed geographic locations as a result of outsourcing or offshoring. Participating in GVCs led by MNEs having advanced technology, internationally recognised brands and global distribution networks offers Chinese firms opportunities to learn and access new knowledge and advanced technology, thus enhancing their innovation

capacity. The expansion of GVCs has been driven by production fragmentation and modularisation of production tasks, the two factors that have lowered technical barriers to entry into technology-intensive sectors such as high-tech industry. Taking advantage of the availability of standardised technology platforms, Chinese firms have concentrated on incremental rather than drastic innovations to introduce differentiated products and in competition with lead foreign companies in both domestic and foreign markets.

To a certain extent, Chinese firms in the ICT industry achieved success with the adoption of the value chain strategy. Most China's high-tech exports are manufactured with imported core technology components and built on top of technology platforms provided by foreign MNEs (Xing, 2014). Assembling mobile phones for foreign vendors remains a major task for many Chinese firms. In this paper, I will use the case of the Chinese mobile phone industry to illustrate the importance of GVCs in the facilitation of innovations and demonstrate how Chinese firms have enhanced their innovation capacity by participating in GVCs.

GVCs, Innovation and Upgrading

GVCs represent a new form of business operation, spanning multiple countries to create goods and deliver them to end consumers in world markets. Production fragmentation and modularisation enable production processes for the dissemination of ready-to-use goods, particularly ICT products, to geographically dispersed locations. Unprecedented liberalisation of trade and investment, innovation in ocean transportation, and profit seeking behaviour of MNEs have been the main drivers of the emergence of GVCs in recent decades (OECD, 2013). Today, most manufacturing commodities are produced and traded along value chains. A typical GVC orchestrates a series of tasks necessary for delivery of a product. Ranging from conception to delivery to end consumers, these tasks include research and development, product design, manufacture of parts and components, and assembly and distribution (Gereffi and Karina, 2011). Firms in different countries work in coordination to complete those tasks. Each firm specialises in one or more tasks in which it has comparative advantage and contributes part of the value added of the final product. GVCs characterise a new division of labour—vertical specialisation along the same product. This specialisation is unlike the specialisation where firms make different products, as analysed by British economist David Ricardo two centuries ago. Compared to conventional specialisation in different products, specialisation in tasks along value chains further refines the division of labour among nations and enhances the efficiency of resource allocation, consequently raising the productivity and economic growth of all economies involved. Three terms, namely, GVC, supply chain and production network, refer interchangeably to the same phenomenon. Economists generally prefer the term GVC because they are interested in the creation of value added and its distribution along value chains. Use of the terms supply chain and production network typically focuses on the production stages within value chains, with the former emphasising who produces what, and the relations between upstream and downstream firms, and the latter paying attention to geographic locations of firms.

A lead firm, which manages the operation of a value chain and decides the relations between firms participating in the chain, is necessary for any meaningful GVCs. If we

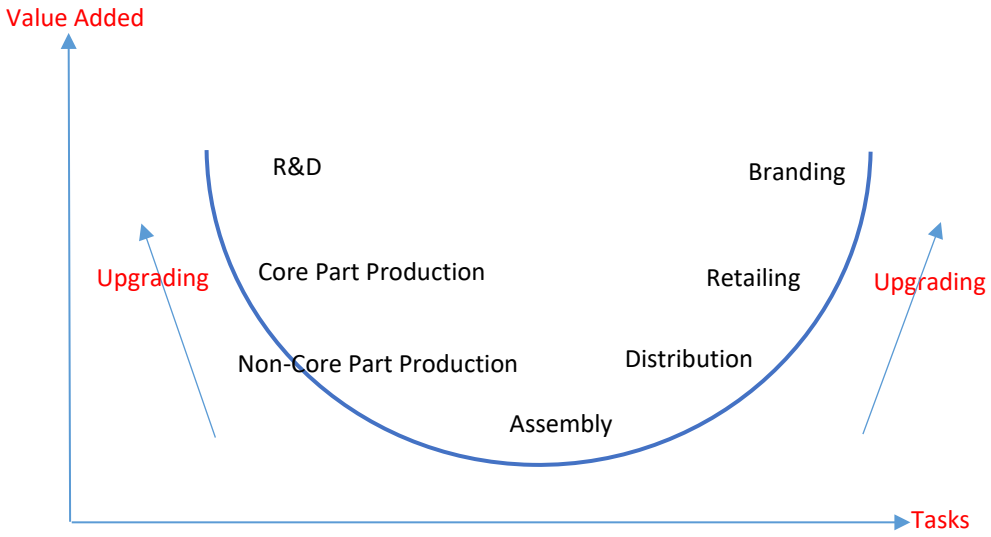
break down the tasks contributing to the production of a product, from supply of the raw materials used, manufacture of the product to the eventual delivery of the product to targeted consumers, we can easily sketch a chain that superficially links all of the firms involved in the process. If the links along a value chain are not bonded with binding contracts, expressly if the relations are simply defined by free market transactions as buyer-seller relations, these value chains add little in terms of innovation. According to their governance structure, GVCs can be classified into producer-driven and buyer-driven value chains. GVCs led by technology leaders in capital-intensive industries such as automobile, aircraft, computer and semiconductor are producer-driven value chains. On the other hand, buyer-driven chains are typically organised by large retailers, branded marketers and branded manufacturers (Gereffi, 1999). The automobile value chains of Japanese auto-maker Toyota and the iPhone value chain of Apple are producer-driven GVCs. Similarly, Walmart, taking advantage of its extensive retail networks in the United States and other countries, has built its buyer-driven GVC by sourcing all goods from contract manufacturers, 60,000 of which are located in China.

Economists define innovation as activities in which a firm applies new notions to the products, processes and elements that generate increased value added. Innovation generally includes two dimensions: product innovation and introduction of a new product; and process innovation refers to introduction of a new process for the manufacture or delivery of goods and services (Greenhalgh and Rogers, 2010). Richard Nelson (1995), a leading expert on innovation, defines innovation as "the processes by which firms master product designs and production processes that are new to them, if not to the world, nation or sector". Nelson's definition emphasises the firm's learning of something new. It is critical to bear in mind that innovation is not a narrowly defined term referring to the creation of a drastically new product that surprises the world. To be sure, a completely new product such as the iPhone with its multi-touch screen and virtual keyboard is definitely a revolutionary innovation for the world. However, learning how to make smartphones with multi-touch screens is also an innovation for a firm imitating the iPhone. Most innovations are incremental achievements based on existing knowledge.

Innovations are not limited to new products, production processes, or technology. New business models and marketing channels, aiming to enhance efficiency and value added, also constitute innovation: "The introduction or implementation of a new or significantly improved product, service or process, a new marketing method or a new way of organizing business, work organization or external relations" (OECD, 1997). For instance, using iTunes to sell songs one by one, not combined in an album (which bundles popular and less-popular songs) is a drastic innovation that has fundamentally changed the business model of the music industry. With iTunes, it is now possible for an artist to achieve fame and financial success with just one hit song (Isaacson, 2011).

Along GVCs, there are many tasks with varying degrees of technical sophistication. The value added created by these tasks also varies substantially. In general, product design, R&D, branding and retailing constitute relatively high value added, while assembly and production of standardised components comprise relatively low value added. The relative importance of tasks in terms of value added can be illustrated intuitively with a smile curve (Figure 1).

FIGURE 1 UPGRADING ALONG GVCs



Source: created by the author based on the smile curve by Stan Shih.

Firms from developing countries generally start with low value added tasks such as assembly when they join value chains governed by foreign MNEs. Many Chinese firms start with assembly of mobile phones for foreign MNEs. Innovation is imperative for firms participating in GVCs if they wish to move up the ladder in value chains and capture high value added. Otherwise, they may fall into a low value-added trap (Sturgeon and Kawakami, 2010). Upgrading includes product upgrading (adding value to products); functional upgrading, such as from pure assembly to design work: and process upgrading (making a production process more efficient) (Morrison, Pietrobelli and Rabellotti, 2008). Upgrading along GVCs and entering high value added segments are a result of innovation activities.

GVCs: A New Path for Innovation by the Chinese Mobile Phone Industry

In any value chain, the lead firm defines products, sets up quality standards and specifies technical parameters. All non-lead firms are obliged to follow the design rules specified by the lead firm. Intensive communication and information exchange between the lead firm and the suppliers is common, and offers a unique channel for non-lead firms to access new knowledge and production know-how. Learning mechanisms within GVCs include face-to-face interactions, knowledge transfer from lead firms, pressure to adopt international standards and training of local workforce by lead firms (Marchi, Giuliani and Rabellotti, 2017). Gereffi (1999) argued that participation in GVCs is a necessary step for industrial upgrading. Plugging into a GVC is similar to engaging in a dynamic learning curve. The transformation of some Asian suppliers from original equipment manufacturers (OEM) to original design manufacturers (ODM) in the apparel industry was significantly supported by their participation in apparel commodity chains.

China has for some time been recognised for its role as the assembly centre of major global brands. Before the emergence of smartphones, Motorola and Nokia used China as a

major assembly base. Since the launch of the first generation iPhone, China has been the exclusive assembler of iPhones. At the peak, Samsung, the No. 1 mobile phone maker in the world, had 65% of its mobile phones assembled in China. Chinese companies which assemble phones for and supply components to these global mobile phone vendors are part of their value chains. The inter-firm linkages between Chinese firms and upstream foreign buyers provide Chinese firms with the access to information about technology and consumer demand, and thus facilitate their innovation activities and upgrading progress along value chains.

Step by step upgrading along value chains from low value added to high value added tasks constitutes a linear model of innovation. For instance, a firm starts with the assembling of mobile phones, before manufacturing the components, and eventually producing mobile phones with its own brand. This is a linear path of innovation, a sequential upgrading along value chains, and differs from the conventional "linear model" that describes the process starting with basic research and then moving into stages of applied research, development and diffusion (Godin, 2006). On the other hand, sourcing core technology from foreign suppliers and jumping directly to brand building lead to a non-linear model of innovation. Chinese original brand manufacturers (OBM), such as Xiaomi, OPPO and vivo, adopted the non-linear model by taking advantage of the modularisation of mobile phone production and successfully broke the monopoly of foreign rivals in both domestic and international markets.

To a large extent, the expansion of GVCs in ICT is attributed to the development of modularity, the division of the manufacture of complicated products into modules—sub-systems that can be designed and manufactured independently. Modularity allows firms to mix and match components so as to produce final products catering to various consumer preferences. By exploring modularity in the design of products, firms can improve their product innovation rate (Baldwin and Clark, 2018).

Firms in developing countries typically face two challenges: a technology gap and a market gap. "Technology gap" refers to the difficulty of accessing necessary technologies and is associated with weak innovation capacity (Schmitz, 2007). Modularity creates the possibility of outsourcing essential technologies and enables firms in developing countries to specialise in value chain tasks for which they have comparative advantage. For example, a mobile phone consists of more than 1,000 parts and components. The modularisation of mobile phone production has simplified the complexity of production and allowed potential entries to focus on non-core technology activities such as assembling. Given their relatively limited technology capacity in core components, say, processors and memory chips, Chinese mobile phone makers entered the industry by sourcing core technological components from foreign MNEs and focusing on incremental innovations, marketing and building brand.

At the early stage of mobile phone development, the production of mobile phones was complicated and vertically integrated within a single firm. In that setting, a few large firms in industrialided countries (e.g. Nokia, Ericson and Texas Instruments) monopolised global markets. In 2001 Wavecom, the French firm that first introduced the GSM model, developed the first module allowing handset makers to easily integrate applications into one

main board. Taking advantage of this modularisation, China's TCL, an electronic appliance maker, entered the mobile phone market (Sun, Chen, Pleggenkuhle-Miles, 2010).

The "turnkey" solution introduced by Mediatek (MTK), a fabless Taiwanese semiconductor firm, is a milestone in the development of the Chinese mobile phone industry. It greatly enhances the degree of modularity of mobile phone production, especially for small phone makers who lack required technology capacities. The turnkey solution, an integrated solution combining hardware and software, is a single chip that combines a baseband platform and multimedia (sound and image) data processing. Using the chip, firms can easily modify product functionality to appeal to preferences of diversified consumers, thus lowering entry barriers significantly (Imai and Shiu, 2010). MTK's turnkey solution boosted the proliferation of "Shanzhai" ("Shanzhai" originally meant counterfeit or imitation products) mobile phone makers, which had previously served as either OEMs or distributors for leading mobile phone brands. However, a few studies argue that Shanzai phones signify indigenous innovation products by small phone makers, and constitute good enough products at affordable prices to meet the needs of targeted customers. Shanzai phone makers gained market share not through technology innovation, but by adopting a novel business model (Hu, Wan and Zhu, 201)

In the age of smartphones, Android operating system (OS) and Qualcomm processor chipsets have become standard technology platforms. Leading Chinese smartphone makers ZTE, Xiaomi, OPPO and Vivo have adopted Android OS for their smartphones. Xiaomi and OPPO built 70% of their phones on Qualcomm's platforms; ZTE and Vivo used Qualcomm's platforms for 60% and 50% of their phones respectively (World Bank, 2019). Android OS platform has lowered technology barriers for brand vendors who could only manufacture white-box phones before. This has facilitated the transformation of a few firms and OEMs into original brand manufacturers; OPPO is a noticeable example (Chen and Wen, 2013). The complexity of today's technology platforms and the demand for product differentiation have enhanced communication and cooperation between foreign suppliers of technology platforms and their downstream Chinese clientele, thus facilitating innovation by Chinese mobile phone makers. For instance, as the major platform supplier to leading Chinese mobile phone makers, Qualcomm welcomes the research teams of these Chinese firms to its headquarters for product development. After intensive interactions with Qualcomm and power chip provider Texas Instruments, OPPO introduced the world's first VOOC (Voltage Open Loop Multi-step Constant-Cur Charging) system for smartphones (Humphrey, et.al., 2018).

In addition, the huge Chinese market, with a population of 1.4 billion, is conducive to marketing-focused strategies based on borrowed technology. In China a focus on the domestic market narrows the marketing gap and leads Chinese mobile phone makers towards a focus on marketing and product differentiation. Compared with their foreign counterparts, Chinese mobile phone makers have a better understanding of Chinese consumers. At the early stage of their development, Chinese mobile phone makers primarily adopted a low price strategy to attract consumers who could not afford expensive foreign brands, and to target consumers in the country's third and fourth tier cities, to which foreign brand vendors had paid less attention. In addition, Chinese makers explored niche markets,

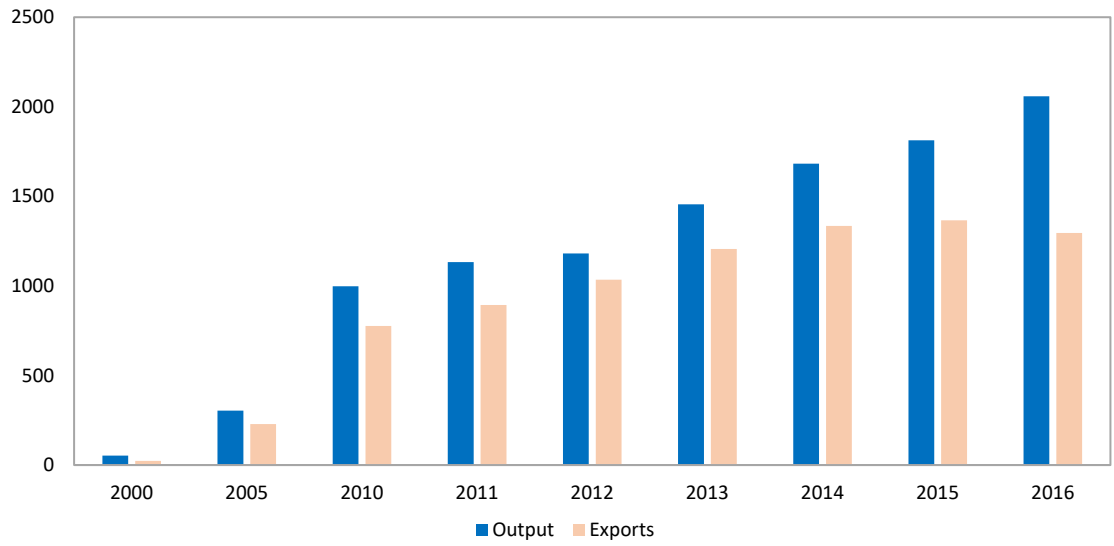
introducing a variety of peripheral functions, such as dual SIM cards, selfie specialisation and long life batteries.

Brandt and Thun (2010) expected that, by adopting value chain strategy, Chinese handset makers "will be more akin to a Dell (which does little product research and design) than Tom Watson's IBM (which was highly vertically integrated)". However, Xiaomi's MIU interface, OPPO's VOOC flashing charging technology and Huawei's Kirin processor are clearly technologically innovative. More importantly, by focusing on marketing and brand building, Chinese mobile phone makers have nurtured their brands, which are now recognised by not only Chinese users but also foreign consumers. For instance, in India Xiaomi has surpassed both Apple and Samsung to emerge as the most popular brand. Brand leadership can boost sales growth, profit margin and pricing power, and gives Chinese mobile phone makers the power to lead the value chains of their products and capture relatively large shares of value added. The bottom line is that brand development is an effective strategy for product innovation (Credit Suisse, 2010)

The Rise of the Chinese Mobile Phone Industry

The rise of the Chinese mobile phone industry is a GVC success story. Despite its technological dependence on foreign technology platforms, the Chinese mobile phone industry has emerged as the largest mobile phone producer and exporter in the world. Figure 2 outlines the trend of Chinese mobile output and exports from 2000 to 2016. In 2016, China produced 2.0 billion mobile phones, 1.3 billion of which were destined for foreign markets. At the beginning of the 21st century, the scale of China's mobile phone output and exports was relatively small. In 2000, China produced 52.5 million mobile handsets, of which 22.8 million, or about 43% of the total, were exported to overseas markets. Driven by the drastic growth of global demand and rapid technology innovation in the sector, the annual output of mobile phones surged to 998.3 million in 2010. Exports grew even faster, jumping to 776 million that year, making China the No.1 exporter of mobile phones in the world.

FIGURE 2 CHINESE OUTPUT AND EXPORT OF MOBILE PHONES

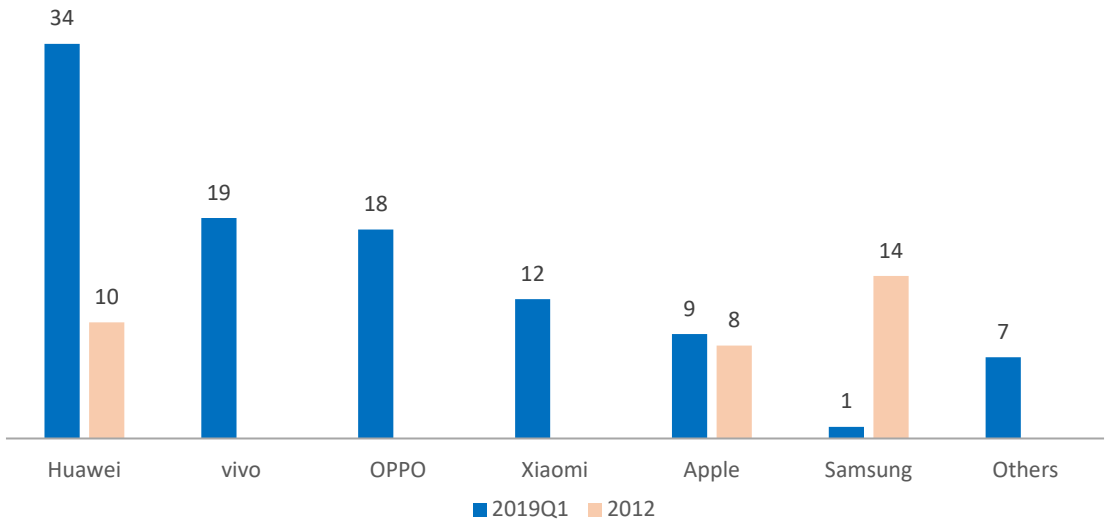


Sources: UNCOMTRDE and China Statistics Bureau.

More importantly, between 2005 and 2015, China's mobile phone exports constantly accounted for more than three quarters of its annual output. At its peak in 2012, China shipped 1.03 billion mobile phones abroad, more than 87% of the year's output. Most of the exported phones were sold under foreign brands and Chinese brand mobile phones almost did not exist in international markets. This unambiguously demonstrates that the Chinese mobile phone industry was then functioning as the assembly centre of global mobile phone production. Participation in value chains governed by leading global vendors and performing assembly tasks were the main drivers of that growth. As a segment of numerous value chains, the Chinese mobile industry simultaneously benefitted from the spillover effects of innovation and marketing activities of leading global vendors, such as Apple and Samsung, that were steadily driving the global demand for mobile phones on an upward trend.

Surging output volume represents the quantitative dimension of China's success in building its mobile phone production capacity. Another important dimension of that success is the brand development by indigenous Chinese firms. In addition to manufacturing handsets for foreign OBMs, the Chinese mobile phone industry successfully nurtured a few mobile phone brands which are competitive with foreign branded mobile phones in both China and abroad. Huawei, OPPO, Vivo and Xiaomi, the most famous Chinese mobile phone brands, have successfully eroded the market share of their foreign rivals and completely reversed foreign domination of the sector in the Chinese market. Marketing research by Counterpoint (2019a) shows that in Q1 of 2019 Chinese brands captured 90% of the Chinese smartphone market, led by Huawei with 34%. The top four smartphone brands in terms of shipments (Huawei, Vivo, OPPO and Xiaomi), all Chinese brands, together accounted for 87% of the market, with Apple retaining a mere 9%. The share of Samsung, the No.1 mobile phone maker in the world, shrank to 1% (Figure 3). Back in 2012, Samsung was the largest vendor in the Chinese market, with 14% market share, while Huawei had only 10%. The market shares of OPPO, Vivo and Xiaomi were negligible.

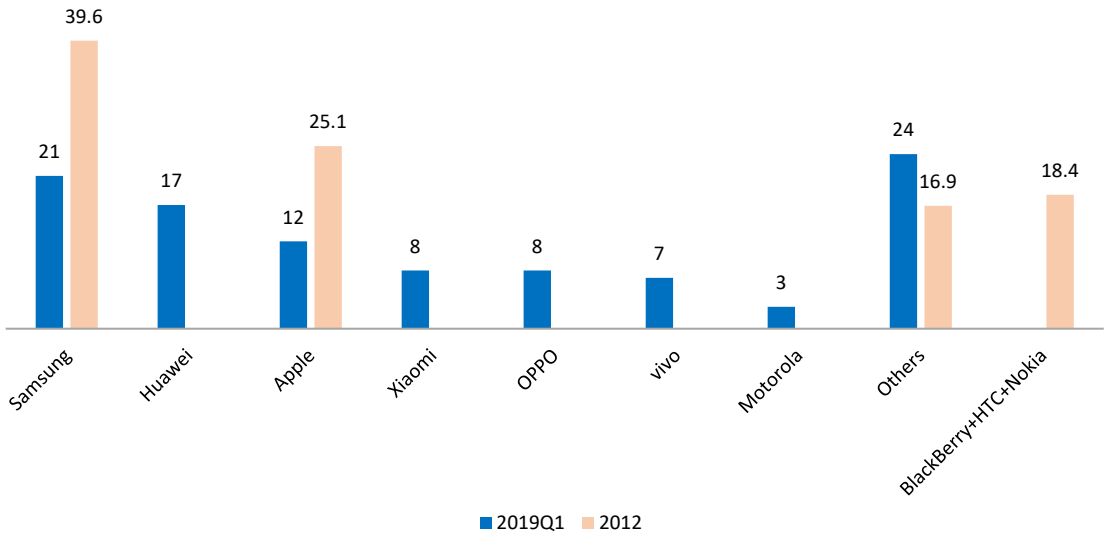
FIGURE 3 CHINESE SMARTPHONE MARKET SHARE (%)



Source： Counterpoint (2019a) and Chen and Wen (2013).

Building on their success in the home market, Chinese OBMs started to sell mobile phones with home-grown brands in international markets, gaining more and more market share, and eventually emerging as globally recognised brands. In Q1 of 2019, Huawei's global market share was 17%, surpassing that of Apple and ranking the second, just four percentage points lower than that of Samsung. In fact, OPPO and Vivo belong to the same company, BBK Electronics Corporation, a Chinese multinational firm specialising in electronics. The combined market share of these two brands was 15%, surpassing that of Apple. Simply put, BBK Electronics Corporation is in reality the third largest mobile phone maker in the world. In 2012, Huawei's market share was about one fourth of Samsung's. OPPO, Vivo and Xiaomi were unknown to foreign consumers. Notably, three bankrupted mobile phone makers, BlackBerry, Nokia and HTC, together accounted for 18.4% of global shipments in 2012. At that time Chinese PC maker Lenovo acquired the Motorola brand. The market share of Motorola became part of Chinese mobile phone maker share, so together they accounted for 44% of smartphone shipments in the global market (Figure 4).

FIGURE 4 GLOBAL SMARTPHONE MARKET SHARE (%)



Source: Counterpoint (2019b) and Chen and Wen (2013).

Moving Up the iPhone Value Chain

The operation of Apple is an exemplary GVC. Apple has outsourced the production of its products to contract manufacturers in various geographic locations and concentrated on product design, R&D and development of software for its operating systems at one tail of the smile curve and marketing and retail at the other. All Apple products, iMac, MacBook Air, iPad and iPhone, are assembled in China. The phrase, "Designed by Apple in California Assembled in China", printed on the back of all Apple products is a hallmark of Apple products.

So far, Apple has released 12 generations of iPhones. With the introduction of the iPhone X, which carries not only the most advanced technologies such as 3D sensing technology, but also a $1,000 price tag, the iPhone has been transformed into a luxury high-

tech gadget. China has been the exclusive assembly base since the first generation iPhone; iPhone 3G, was released in 2007. As the centre of the iPhone production, the Chinese mobile phone industry benefits significantly from the popularity of the iPhone in the world market, which automatically translates into demand for the services and periphery components supplied by the Chinese mobile phone industry. This has significantly promoted the growth of the Chinese sector in the last decades.

According to Xing and Detert (2010), Foxconn, a Taiwanese company with many production facilities in mainland China, received only $6.5 or 3.6% of the total manufacturing cost and roughly 1.3% of the retail price for assembling a ready-to-use iPhone 3G. It consists of the whole value added captured by China in the process of manufacturing the iPhone 3G. To avoid the low value-added trap and take advantage of the learning opportunity offered by GVCs, upgrading and moving into relatively high value-added segments are crucial for Chinese firms involved in the iPhone value chain. To assess the upgrading status of Chinese firms participating in the value chain, it is necessary to examine whether the number of Chinese firms involved in Apple's value chains has increased, the range of tasks performed by Chinese firms has expanded and the technological sophistication of the tasks has risen.

Upgrading along the iPhone value chain is highly rewarding financially. In general, future uncertainty discourages firms from engaging in innovation efforts. Once a Chinese firm joins the army of Apple supplier companies, hundreds of millions of Apple users around the world will be potential customers for that firm's products or services. The predictable and lucrative prospect motivates Chinese firms to raise the quality of their products up to the standard of Apple. This is an example of innovation activities inspired by GVC participation. Seamus and Yutao (2016) found that Chinese firms have played an increasingly important role in Apple's value chains. In 2014, of 198 companies in Apple's supply chain, 14 were Chinese. A few of them supplied core components, for example displays and printed circuit boards; this suggests that Chinese firms have strengthened their presence in the value chains controlled by Apple.

Based on teardown data, which provides detailed information about suppliers of the iPhone X and prices of parts and components, it shows that all core components embedded in the printed circuit board assembly (PCBA), including processor, DRAM, NAND, display and camera, are supplied by Apple, Qualcomm, Broadcom, Samsung, Toshiba, Sony and other non-Chinese companies. Indigenous Chinese companies manufactured only a small portion of non-core components. Besides Foxconn, there are 10 local Chinese companies participating in the value chain of the iPhone X. Their tasks go beyond simple assembly task and spread over relatively sophisticated segments. Table 1 lists Chinese firms and their corresponding tasks in the production of the iPhone X.

TABLE 1 TASKS PERFORMED BY CHINESE FIRMS FOR IPHONE 3G AND IPHONE X

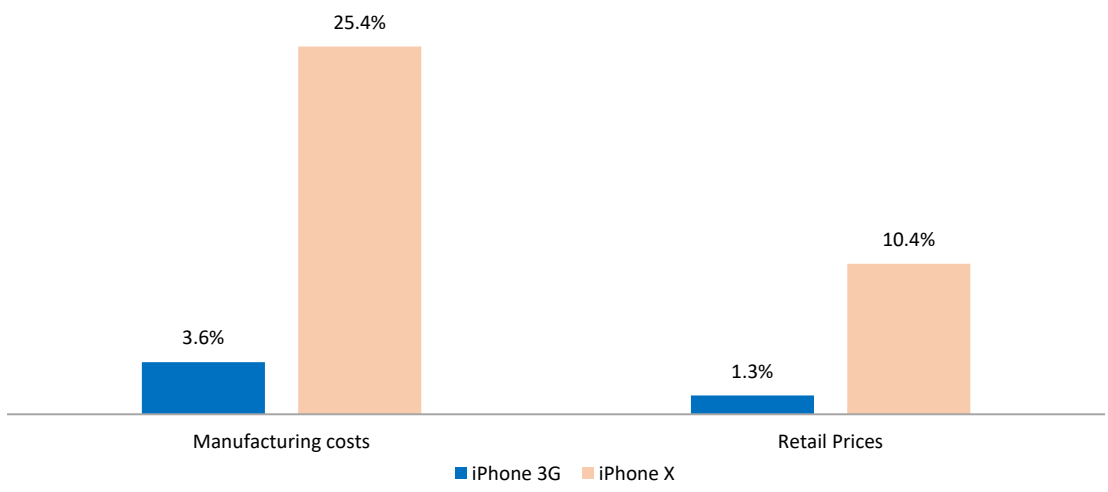
3G iPhone (2009)	iPhone X (2018)
• Assembly (Foxconn)	• Assembly (Foxconn); • Function parts for Touchscreen Module (Anjie Technology); • Filter for 3D sensing Module (Crystal Optech); • Coil Module for wireless charging (Lushare Precision); • Printed Circuit Board (M-Flex); • Speakers (Goertek); • RF Antenna (Shenzhen Sunway); • Battery Pack (Sunwada); • Glass cover (Lens Technology); • Stainless Frame (Kersen Technology); • Camera Module (O-Film)

Source: Xing and Detert (2010) and the teardown data provided by the author's technical supporting team.

Sunwada, a leading Chinese battery maker, supplies the battery pack. Sony batteries were used in the early models of the iPhone; Sunwada's supplanting of Sony as a battery pack supplier is a significant upgrading of Sunwada along the iPhone value chain. Kersen Technology provides the iPhone stainless frames and Lens Technology manufactures the glass covers. The stainless frame and glass back cover together cost $53, about 13% of the total manufacturing cost and more than 11 times the assembly fee of $4.5. The iPhone X is the first iPhone with a glass back cover. Chinese companies Anjie Technology and Lushare Precision are also involved in the manufacturing of iPhone X touch screens and 3D sensing modules, respectively. Touch screens and 3D sensing modules are critical technological components of the iPhone X. The former translate users' finger movements into data that can be interpreted as commands, while the latter is a key element of the facial recognition system, a new feature introduced in iPhone X. Chinese company Dongshan Precision joined the suppliers of Apple by acquiring American company M-Flex; it now supplies the printed circuit boards for iPhone X at $15 per unit. Chinese companies Goertech, Shenzhen Sunway, Crystal-Opetch and O-film provide functional parts: speakers, RF antennas, filters and camera modules, respectively. The involvement of these Chinese firms, albeit in non-core technology segments of the iPhone X value chain, indicates that the Chinese mobile phone industry as a whole has moved to the upper rungs of the iPhone value chain ladder.

According to the teardown data, the total bill of materials of the iPhone X is $409.25, with Chinese firms jointly contributing $104, or about 25.4% of total manufacturing cost. A complete value chain consists of pre-production, production and post-production activities. For estimation of the domestic value added in a country's exports and to fairly evaluate bilateral trade balances with its trading partners, it is appropriate to use the manufacturing cost of a product as a benchmark. For assessment of the value captured by Chinese firms in the whole iPhone X value chain, this analysis went beyond production and used retail price as a benchmark, since retail price proxies total value added of the iPhone X. Findings show that Chinese firms together captured 10.4% of the value added in iPhone X's retail price of $1,000, much higher than that for iPhone 3G (Figure 5).

FIGURE 5 CHINESE VALUE ADDED EMBEDDED IN IPHONE 3G AND IPHONE X



Source: Xing and Detert (2010) and author's calculation.

Therefore, compared with iPhone 3G, more Chinese firms are involved in the production of iPhone X and perform more diverse tasks and capture higher value added. This implies significant upward movement of Chinese firms along the iPhone value chain. All of Apple's suppliers are required to satisfy the high quality and technology standards defined by Apple. The pressure to meet the standards of Apple facilitated the upgrading process of these firms and their innovation activities.

OPPO and Xiaomi: a GVC Success Story

OPPO is one of the most popular mobile phone brands in the Chinese market. In the first quarter of 2019, it ranked No. 3 after Huawei and Vivo, with 18% market share (Counterpoint, 2019a). "Designed by OPPO Assembled in China" is printed on the back of OPPO phones. The statement is a replica of a similar phrase on the back of the iPhone, which is a little awkward as OPPO is clearly a 100% Chinese company. OPPO intends to use the statement to convey a message to its users: OPPO phones are made by state-of-the-art technologies and China's role is limited to assembly. The statement is self-evident in that OPPO phones are products of GVCs. By providing an excellent selfie experience, OPPO smartphones have achieved widespread popularity among the young. OPPO markets its phones as camera phones in commercials, to make a different statement from other brands. The company operates a nationwide network of 200,000 stores to sell its products in China. It generally pays a much more generous commission than the industrial average to motivate its salespersons (Wang, 2016). Globally, OPPO shipped 25.7 million units of smartphones in the first quarter of 2019 and held fifth position among leading mobile phone vendors (Counterpoint, 2019b)

To understand the dependence of OPPO on foreign technology platforms, the analysis uses the teardown data of the OPPO R11s, a premium smartphone released in 2017, running on Andriod OS, to examine the suppliers of OPPO in detail. The teardown data shows that all core components were sourced from foreign suppliers. The phone is powered

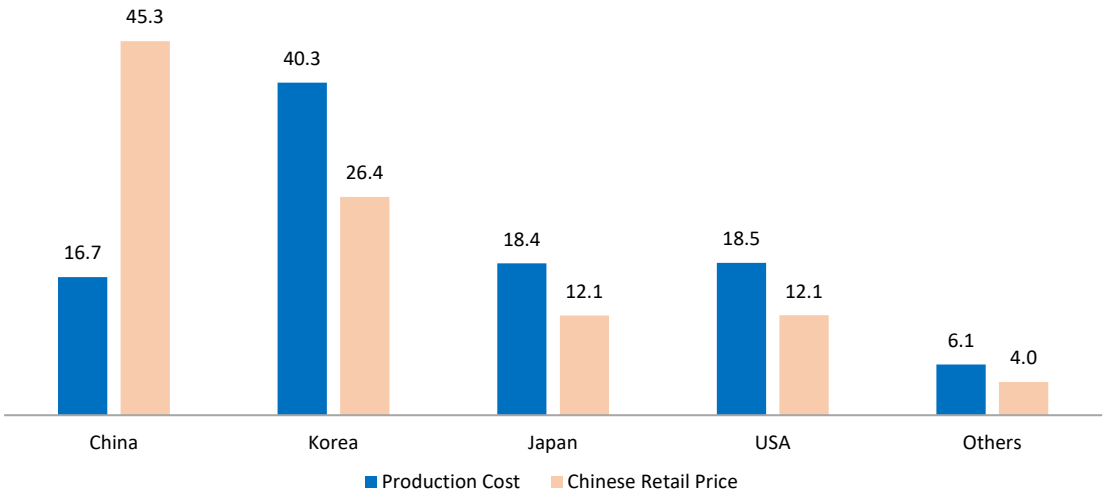
by Qualcomm's mid-range Snapdragon 660 processor, coupled with an embedded multi-chip package (eMCP) by Samsung. It features a 6.1-inch full screen AMOLED display also by Samsung. All components embedded in the PCBA are supplied by foreign companies, particularly Qualcomm, Samsung, TDK and Muruta. SONY supplies the rear camera, Samsung the front camera for selfies. The total value added of foreign companies accounts for 83.3% of the total manufacturing costs, consistent with the statement "assembled in China" (Table 2). A few Chinese firms provide a limited number of non-core components such as the fingerprint module (by O-film) and the battery (by Sunwada).

TABLE 2 FOREIGN TECHNOLOGY AND SUPPLIERS OF THE OPPO R11s

Operation System	Andriod (US)	Total Foreign Value Added
CPU: Snapdragon 660	Qualcomm (US)	83.3% of total manufacturing cost of $293.18
Memory: eMCP	Samsung (Korea)	
Display : 6.01inch 1080x2160 pixels	Samsung (Korea)	
Dual Camera	Sony (Japan)	
Front Camera	Samsung (Korea)	

Source: Xing and He (2018).

FIGURE 6 DISTRIBUTION OF THE OPPO R11S VALUE ADDED BY COUNTRY



Source: Xing and He (2018).

Figure 6 shows the estimated distribution of value added of OPPO R11s by country. The total bill of materials of the phone is $293.18. Korean companies Samsung and Hynix together contributed 40.3% of the total manufacturing cost. The second largest source of value added is 18.5%, from the United States. The contribution of Japanese companies Sony, Muruta and others is estimated at 18.4%, almost the same as that of the United States. Chinese companies accounted for the smallest share of value added. However, if we take the retail price RMB2,999 as a benchmark, the cross-country distribution of value added is dramatically different: China emerges with the largest share of total value added, about

45.3% of the retail price, which shows the power of brand ownership: that significantly high share is attributed to brand value and the corresponding retail service (Figure 6).

Xiaomi is the fourth largest mobile phone maker in the world. It shipped 27.8 million smartphones globally in 2019 (Counterpoint, 2019b). Unlike OPPO, Xiaomi is a factory-less maker and has no assembly facilities. It outsources the production of its phones to contract manufacturers. Xiaomi is the first Chinese mobile phone vendor to sell phones exclusively online. The secrets of Xiaomi's success include selling a premium phone at about half the price of its competitors; fast-flashing sales; and nurturing a community of users. Xiaomi's largest foreign market is India where it surpassed Samsung to become the No.1 smartphone vendor.

Similar to OPPO smartphones, all Xiaomi phones run on Android OS and are designed based on Qualcomm chipsets. Xiaomi, however, has developed a unique MIUI interface based on Android OS and installed it on Xiaomi phones to differentiate it from other brands. The analysis employs the case of the flagship device MIX 2 released in the second half of 2017 to demonstrate Xiaomi's reliance on foreign technology. The teardown data of MIX2 reveals that it is powered by a top-end Qualcomm Snapdragon 835 processor, which costs $62.56, the most expensive part in the PCBA of the MIX2. It has a 6GB NAND flash memory supplied by the Korean company Hynix and 64GB Dynamic random access memory manufactured by Samsung. The Xiaomi MIX 2 features a 5.99 inch 1080x2160 pixel display produced by Japan Device Inc. Sony supplies the camera embedded in the phone. Chinese companies are mainly involved in the provision of non-core components and services. For instance, BIYADI Electronics supplies the frame of the phone and the battery company SCUD provides the battery. Table 3 lists major foreign technology suppliers.

TABLE 3 FOREIGN TECHNOLOGY AND SUPPLIERS OF THE XIAOMI MIX 2

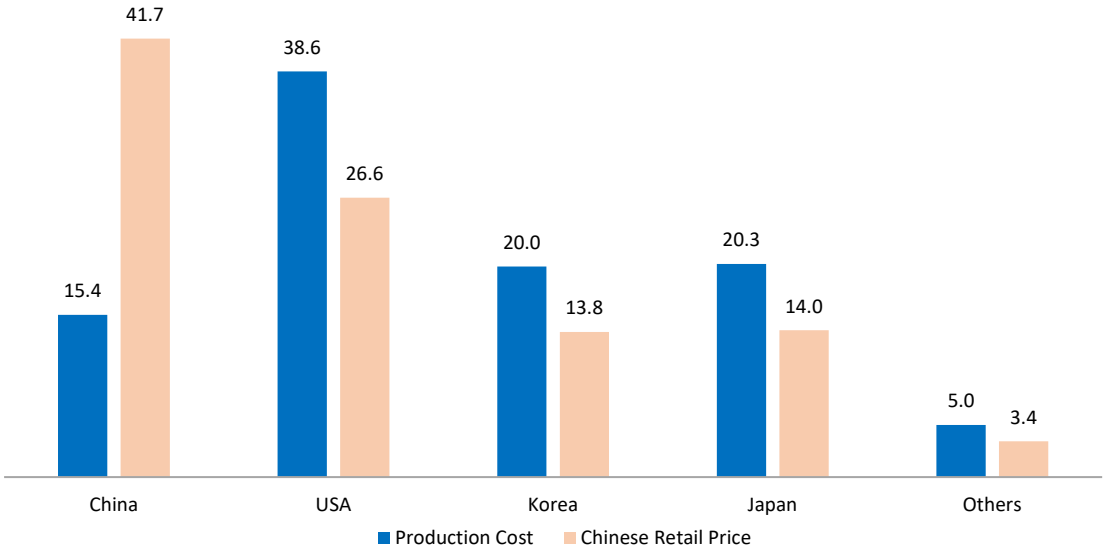
Operating System	Android (US)	**Foreign Value Added**
CPU: Snapdragon 835	Qualcomm (US)	84.6% of the total manufacturing cost $335.98
NAND 6GB	Hynix (Korea)	
DRAM 64GB	Samsung (Korea)	
Display: 5.99 inch, 1080x2160	JDI (Japan)	
Camera	SONY (Japan)	

Source: Xing and He (2018).

Foreign companies together accounted for 84.6% of the value added of manufacturing the Xiaomi MIX 2. Specifically, US companies captured 38.6% of the value added, the highest among all country groups, followed by Japanese companies' 20.3% and Korea's 20.0%. Similar to the case of OPPO R11s, Chinese companies' contribution to the value added of the MIX 2 is relatively small, about 15.4% of total production cost (Figure 7), suggesting that the involvement of Chinese companies in the value chain of Xiaomi is limited. The retail price of the MIX is RMB3,299. If the value added generated by Xiaomi's brand and the retail service is included, the share of the Chinese value added is 41.7%,

significantly higher than that when only production is considered. Again, the brand ownership has raised the Chinese value added.

FIGURE 7 DISTRIBUTION OF XIAOMI MIX 2'S VALUE ADDED



Source: Xing and He (2018).

The teardown data of OPPO R11s and Xiaomi MIX 2 suggest that foreign technology remains indispensable for Chinese brand mobile phones. Even though OPPO and Xiaomi have emerged as a global brand, the innovations of the two companies are incremental and marginal. Instead of targeting drastic technology advancement for catching up, they emphasise product differentiation, brand building and business model by taking advantage of the availability of technology platforms. The successes of OPPO and Xiaomi indicate that GVCs provide a non-linear model of innovation and firms of developing countries can enter high-tech industry and emerge as lead firms by sourcing necessary technologies.

The innovation path of Huawei differs from that of Xiaomi and OPPO. It is the largest mobile phone maker in China and the second largest in the world. Huawei is considered the most innovative Chinese company. In 2018, it invested $15.3 billion in R&D and even outspent Apple (Bloomberg, 2019). Compared to OPPO and Xiaomi, the innovations of Huawei are relatively more technology-oriented. It has developed the Kirin processor, which is used in the latest model, Huawei Pro 30. According to the teardown data of the Japanese firm Fomalhaut Techno Solution, Huawei Pro30 is powered by the Kirin processor of HiSilicon, a subsidiary of Huawei, suggesting that Huawei has developed the technological capacity to produce a chip set which can substitute Qualcomm's chipsets, currently adopted by most Chinese mobile phone makers (Table 4). The Kirin processor marks the highest level of technological innovation by the Chinese mobile phone industry. In addition, the Huawei Pro 30 incorporates an OLED display manufactured by Chinese company BOE Technology. The OLED display is the most expensive part embedded in the Huawei Pro30. Due to these two key components, the Chinese value added in Huawei Pro 30 reached 38.1%, much higher than that in OPPO R11s and Xiaomi MIX 2. Samsung, LG and JDI have been dominant in OLED display market. The adoption of BOE Technology's

OLED display by Huawei is a noticeable encroachment of the monopoly of the foreign companies.

TABLE 4 FOREIGN TECHNOLOGY AND SUPPLIERS OF HUAWEI PRO 30

Operating System	Android (US)	**Foreign Value Added**
CPU	HiSilicon (China)	61.9% of total manufacturing cost
NAND	Samsung (Korea)	
DRAM	Micron Technology (US)	
Display	BOE Technology (China)	

Source: Fomalhaut Techno Solution.

Concluding Remarks

The rise of the Chinese mobile industry is impressive and unique. On the one hand, China has become the largest mobile phone maker and the largest exporter in the world. Of the top five global mobile phone brands, three are Chinese brands: Huawei, Xiaomi and OPPO. On the other hand, all Chinese smartphones depend on foreign technology platforms. They run on the Android OS owned by Google and powered by Qualcomm chipsets. However, that technology deficiency has not hindered the emergence of the Chinese mobile phone industry. The value chain strategy of sourcing necessary technology platforms and concentrating on product differentiation and incremental innovation explain the significant achievement of the Chinese mobile phone industry. GVCs facilitated by modularisation provide a unique path for Chinese firms to enter the industry and bypass technological barriers. As latecomers, Chinese firms had to begin as contract manufacturers, assembling mobile phones for foreign vendors. The emergence of home-grown brands in global markets and their upgrading along the value chain of the iPhone suggest that Chinese firms are capable of moving up the value chain and that their innovative activities performed a critical role when in competition with foreign rivals.

The development of GVCs makes it possible to achieve a non-linear model of innovation, though the GVC strategy is not risk-free. All the cases presented here refer to technology platforms owned by foreign companies, mainly American companies Google and Qualcomm. The efficiency and effectiveness of the GVC strategy is based on the assumption that Chinese firms are able to purchase necessary technologies via fair market transactions. If unexpected shocks lead to the disruption of the supply chain, for instance the US blacklist of Huawei, the operation of the Chinese firms would suffer devastating disruption.

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