Is China's Innovation a Threat to the South Korea-China Economic Relationship?

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This paper reviews China's technological rise and assesses whether it poses a threat to the South Korean economy. In terms of comparative advantage between the two countries, many experts have long believed that China's strength is low-cost labor and Korea's is technology and capital. However, this has changed as China's economy grows. Now China has enough capital to invest in its economy. Some scholars even argue that China has the potential to meet its "innovation imperative" and emerge as a driving force in innovation on a global level.[1] This paper examines the Korea-China economic relationship from the innovation productivity perspective, organized into sections: briefly introducing the Korea-China economic relationship; describing the technological rise of China, based on recent data; developing the model to analyze the innovation productivity of China and report the estimation results; evaluating the concern of the South Korean semiconductor industry; and presenting conclusions.

Korea-China Economic Cooperation and the Necessity for a New Relationship

Despite fewer than 30 years of formal diplomatic relations, Korea-China relations have dramatically deepened in various dimensions including diplomatic, economic, and social relationships due to geographical proximity, the mutually supportive structure of the two economies, and historical and cultural ties. The two established a formal diplomatic relationship on August 24, 1992. In 1998, they upgraded their relationship to a "collaborative partnership for the 21st century," and it further developed into a "comprehensive partnership" in 2003. In 2008, the diplomatic relationship was again upgraded to a "strategic cooperative partnership," which is the highest level except for a military alliance, strengthening cooperation in the international arena and also dealing with long-term issues (including the North Korea issue).[2]

Accompanying the development of diplomatic relations, the economic relationship has been strengthened. In global industrial value chains, the two countries have maintained close relations by China specializing in providing labor and land and Korea in supplying technology and capital. As a result, the amount of trade totaled $268.6 billion in 2018, a 42-fold increase from $6.4 billion in 1992. China became Korea's largest trade partner. Korea became China's largest source of imports and its third-largest trading partner. Human exchanges also increased steadily, from 130,000 people in 1992 to 8,990,000 in 2018.

Four stages of development of economic cooperation between the two countries can be discerned 1) the early period (1992-2000); 2) the growth period (2001-2008); 3) the expansion period (2008-2015); and 4) the transition period (2015-the present). In 1992-2000, the early stage of economic cooperation, China actively promoted reforms and an open market policy after Deng Xiaoping's 1992 Southern Tour speeches. China supplied low-wage labor, provided factory rent assistance, and offered various tax benefits to attract foreign firms. Korean companies made inroads in labor-intensive manufacturing industries such as textiles, apparel, leather, and accessories. In particular, most Korean companies entered into Northeast China (Liaoning, Jilin, Heilongjiang, and Shandong provinces), including areas where ethnic Koreans lived as well as those geographically close to Korea.

2001-2008 is the period when economic cooperation reached a high volume as China's accession to the WTO improved its external openness, infrastructure, and investment environment. Korean conglomerates invested in large cities, such as Beijing, Shanghai, and Tianjin, and China's east coast provinces including Jiangsu and Guangdong, which all have geographical advantages. Most Korean companies established local headquarters and sales and production bases in these areas. It was a period of active "fleet type" investments, which featured conglomerates and their small and medium-sized subcontractors simultaneously branching out into China's market. In terms of global value chains, Korean and Chinese manufacturers set up a complementary collaboration system. Korea increased its intermediary goods exports to China, which enlarged China's final goods exports toward developed markets such as the U.S. and Europe.

From 2008 to 2015, there was an expansion of trade and investment between Korea and China. Furthermore, both countries strengthened financial and monetary cooperation in coping with the global financial crisis triggered in the U.S. in 2008. During this period, the two governments responded jointly to the crisis by signing currency swaps, and initiated discussion on the Korea-China FTA to expand trade and investment. However, at the same time, the burden for labor-intensive and small and medium-sized businesses gradually increased since there was an increase in China's land and labor costs, and even change in Chinese government's foreign investment policy from attracting all types of foreign investments to inviting selective foreign investments that promote its technology-intensive industries and upgrade its industrial structure.

From 2015 to the present, as China pushed a strategy of import substitution industrialization and technological sophistication, the economic relationship between Korea and China was becoming more competitive rather than more cooperative. The two countries opened a new era of trade and investment through the agreement (May 2015) and effectuation (December 2015) of the Korea-China FTA. Moreover, recently the two parties started negotiations to enhance the effectiveness of the ongoing bilateral FTA, expanding cooperation in the financial and monetary sectors, such as Korea participating in the China-led Asian Infrastructure Investment Bank (AIIB). However, facing limitations of the quantity-oriented, export-led economic growth model that has continued for over 30 years, China has shifted its growth strategy to domestic-led growth since 2008 and has simultaneously promoted a qualitative development strategy that includes ambitious innovation-driven goals such as "Internet Plus," "Made in China 2025," and "Mass Entrepreneurship and Mass Innovation." Accordingly, as the share of high-technology manufactures in China's exports grows, economic relations between Korea and China are shifting from a vertical to a horizontal division of labor, and from complementary to competitive relations.

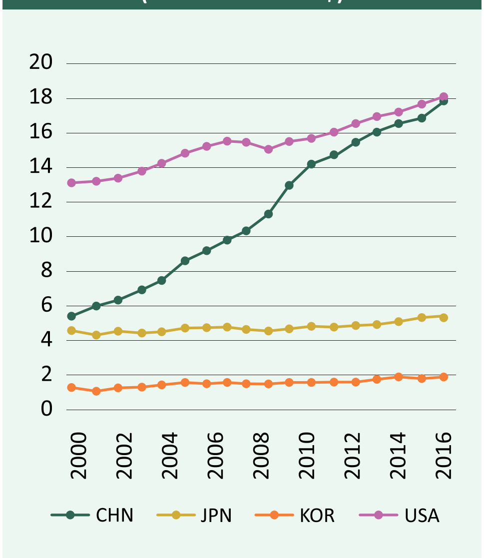
A long-standing formula of Korean companies exporting intermediary products to China and China exporting processed final goods to the world, is not working anymore in almost all areas: intermediate goods (system semiconductors), capital goods (liquid crystal devices), and low-priced consumer goods (home appliances and mobile phones). It is time to find a new model of cooperation, and the key factor that resulted in this change is the technological innovation of China. In the following section, I discuss China's rise, focusing on its technological capabilities.

The Rise of China

China sustained an annual growth rate of gross domestic product (GDP) that averaged about 10 percent for more than three decades, driven by reforms that unlocked China's huge growth potential and created conditions for the country to catch up rapidly with higher-income economies. Figure 1 shows that China caught up to the U.S. in real GDP by 2017.

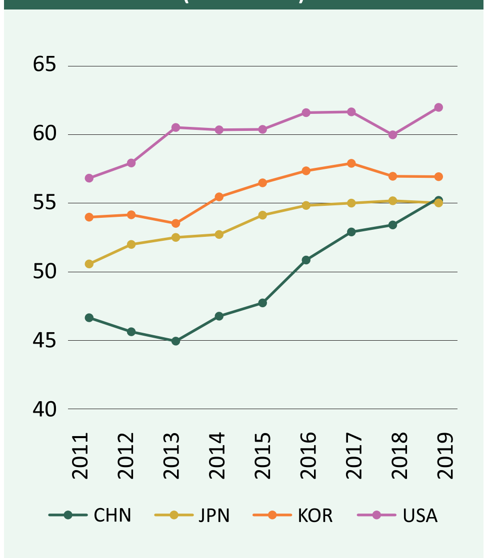
One of the key factors that explain the rise of China is its WTO entry in 2001, which accelerated reforms and productivity growth. It shows a remarkable example of how opening an economy and integrating into global value chains can strengthen competitiveness, enhance productivity, and facilitate the absorption of advanced technologies. Not only is China now the world's largest exporting country, it also plays an increasingly important role in global value chains by exporting more and more sophisticated goods. Decades of high-speed economic growth have enabled the Chinese government to allocate more resources to research and development (R&D). Various international assessments indicate that China has been gradually improving its national innovation capacity. According to the Global Innovation Index, developed by the World Intellectual Property Organization (WIPO), INSEAD, and Cornell University, China's innovation capacity has been improving rapidly since 2013 (Figure 2).

Figure 1. Real GDP at current PPPs (in trillion 2011 US$)



Source: Penn World Table v 9.1

Figure 2. Global Innovation Index (Total Score)



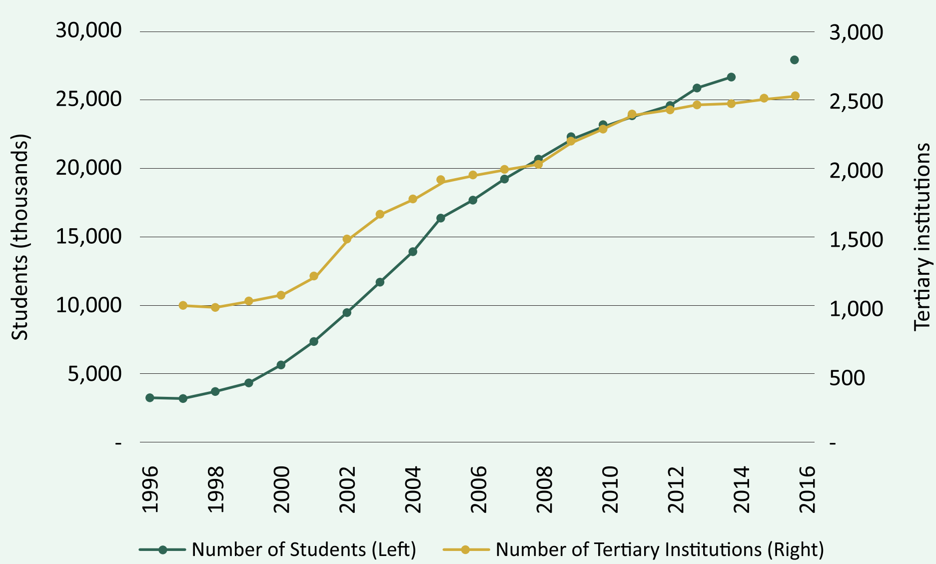
Source: Cornell, INSEAD, WIPO, globalinnovationindex.org.

Human Capital and Future Growth

China's human capital capabilities are the foundation of its growing innovation capabilities. The quantitative and qualitative improvement of education raises the ability of ordinary workers to adapt to and use new technologies, which is related to the national dispersion of technology. Furthermore, human capital investment promotes the discovery of high technology and innovations and strengthens the research capabilities of China's universities, research institutes, and businesses.

Its higher education system has undergone major expansion and transformation over the past two decades. Since Deng Xiaoping's 1992 Southern Tour and the establishment of a socialist market economic system, China has been upgrading university education through targeted programs. The 1995 "Project 211" and 1998 "Project 985" were launched to strengthen the country's top 100 tertiary education institutions, particularly their research capacity.[3] The two projects focused on efficiently allocating limited government resources to achieve qualitative improvement of tertiary education. Since the announcement of "Project 985," the number of universities and students has surged (Figure 3).

Figure 3. Number of Universities and Students in China, 1996-2016

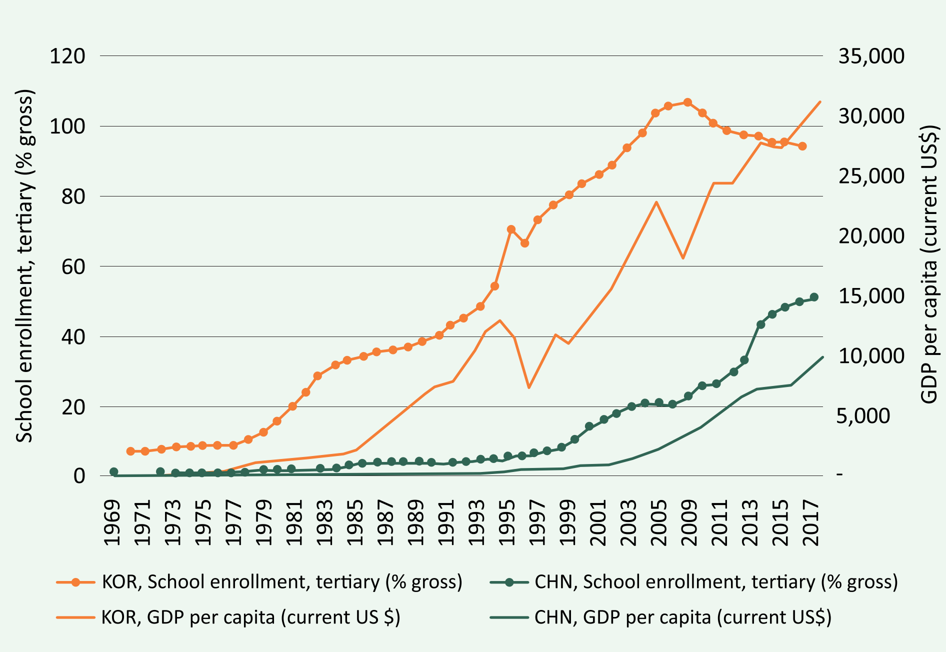


Source: CEIC

China announced the National Outline for Medium- and Long-Term Educational Reform and Development (2010-20) in 2008, and the "Double World Class Project"[4] in 2015, to succeed earlier programs tasked with promoting the best universities to world class. A total of 42 universities and 456 disciplines in 95 universities were selected to receive funding from the central and local governments in order to improve facilities and infrastructure, to conduct research and development, and to attract high-level academics. Heavy emphasis was put on developing the hard sciences or practical disciplines. For example, among the 456 fields that were selected to become world-class, the humanities and social sciences only account for 11 percent and 18 percent, respectively. By contrast, science and engineering constitute the largest share of 49 percent, followed by medical science and agriculture and forestry 22 percent.[5] This meant that once again China entered a new stage of human capital development. In 2019, China announced "China Education Modernization 2035" (Education 2035) as another medium-term strategy for developing its higher education system. Associated with another ambitious strategic plan "Made in China 2025," China probably launched the "Education 2035" strategy in order to address the labor market's changing demands in light of the ongoing Fourth Industrial Revolution.

Currently, China runs one of the world's largest education systems, with more than 270 million students enrolled at various levels. However, the quality of China's human capital, not the quantity, will be the backbone of the knowledge economy. Enrollment in tertiary education still lags behind high-income countries in 2018. The current tertiary enrollment rate of 48.1 percent is similar to that of Korea in 1994 (Figure 4). Prioritizing human capital investments and reinforcing China's education and training system will be essential for transforming to innovation- and productivity-led future development of China. If the "Education 2035" strategy succeeds, China will be able to establish the world's leading talent pool by 2035.

Figure 4. GDP per Capita and Tertiary Enrollment Rate, Korea and China

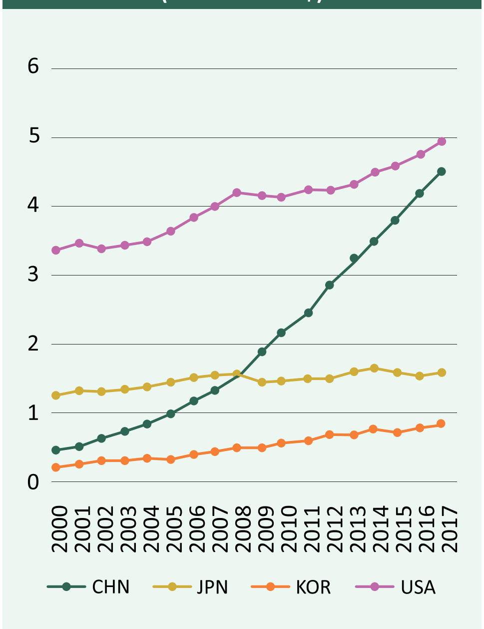


Source: World Bank, WDI

R&D

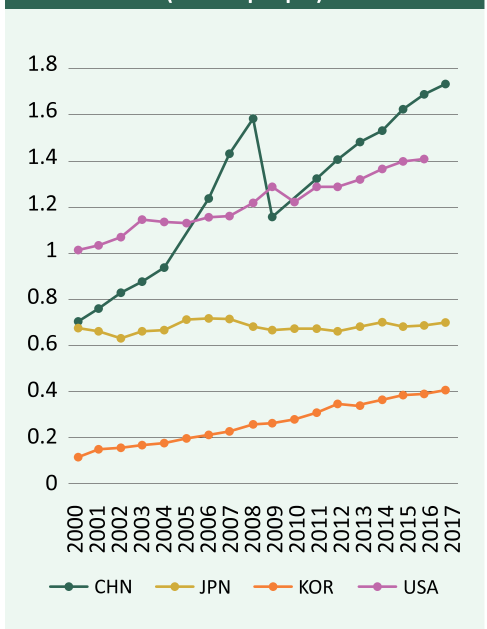
China has built a large and extensive national innovation system to accumulate and allocate resources that enable supplying the innovation and technologies required for productivity growth. Evaluations of China's innovation capacity differ across various international assessments, but they all indicate that gaps have been steadily narrowed between China and high-income countries. In particular, R&D investments and the number of patent applications have risen rapidly in recent years. This transition was propelled in part by government policies. For instance, the 12th Five-Year Plan (2010-2015) set an R&D spending target of 2.2 percent of GDP by 2015, which it only marginally missed by 0.13 percent. Since then, China has renewed its support through the 13th Five-Year Plan (2015-2020), whose goal is 2.5 percent by 2020. China is already making notable progress in pursuit of this goal. In 2018, it reached 2.18 percent of GDP, compared with the Organization for Economic Cooperation and Development (OECD) average of 2.4 percent. China's R&D expenditures increased almost 11-fold from 2000 to 2017 – from $41 billion to $445 billion (Figure 5). Presently, China spends more on R&D than Japan, Germany, and South Korea combined, and second only to the United States in terms of gross expenditure. Its total spending on R&D accounts for around 20 percent of global spending on R&D. According to some estimates, China will overtake the U.S. as the top R&D spender by 2020.[6]

Figure 5. R&D Expenditure (100 billion US$)



Source: OECD

Figure 6. R&D Researchers (million people)



Source: OECD

Some might argue that China has a small number of R&D researchers relative to its population size.[7] However, technology has characteristics of a public good, as well as those of a private good. The proprietary aspect makes it profitable for firms to invest in its advance. The public aspect enables the community as a whole to benefit from technological advances.[8] Once the innovation has occurred, all people share the outcome so that the aggregate number or the national capacity matters. China had about 1.7 million scientists working on R&D in 2017 (Figure 6), maintaining the world's largest pool of R&D personnel for the sixth year in a row.

Figure 7. Patent applications (Total, million)

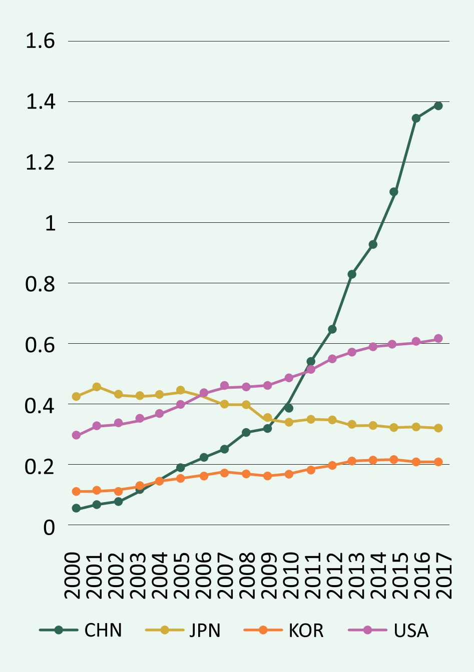
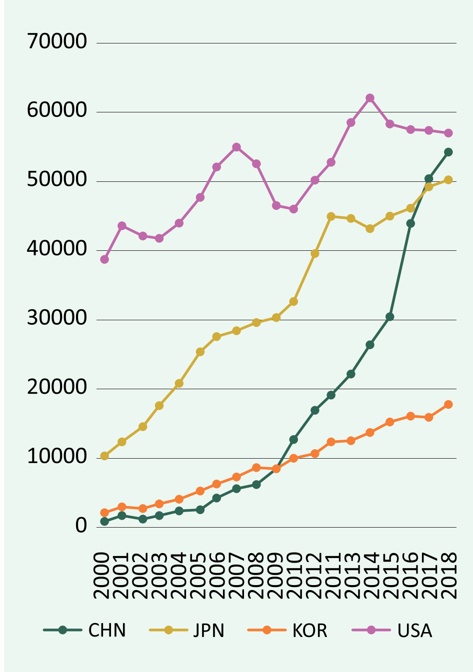


Figure 8. PCT applications by filing date



In line with higher investment in R&D, China's patenting has increased dramatically over the last half-decade (Figure 7 and Figure 8). Although their quality varies, China has the world's largest number of domestic patents, with nearly 1.4 million applications in 2017. In 2018, China filed the world's second-highest number of applications under the Patent Cooperation Treaty (PCT),[9] with Huawei the most frequent PCT filer in the world (Table 1).

Table 1. Top PCT applicants

Ranking	Applicant	Origin	Published PCT applications		
			2016	2017	2018
1	HUAWEI TECHNOLOGIES CO., LTD.	China	3,692	4,024	5,405
2	MITSUBISHI ELECTRIC CORPORATION	Japan	2,053	2,521	2,812
3	INTEL CORPORATION	US	1,692	2,637	2,499
4	QUALCOMM INCORPORATED	US	2,466	2,163	2,404
5	ZTE CORPORATION	China	4,123	2,965	2,080
6	SAMSUNG ELECTRONICS CO., LTD	Korea	1,672	1,757	1,997
7	BOE TECHNOLOGY GROUP CO.,LTD	China	1,673	1,818	1,813
8	LG ELECTRONICS INC.	Korea	1,888	1,945	1,697
9	TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)	Sweden	1,608	1,564	1,645
10	ROBERT BOSCH CORPORATION	Germany	1,274	1,354	1,524

Source: WIPO, Patent Cooperation Treaty Yearly Review 2019, https://www.wipo.int/publications/en/details.jsp?id=4424

Examining PCT patents is more important than looking into domestic patents since the current globalization of R&D activities is reflected in international patenting. An application filed under the PCT is commonly referred to as an international patent application. Also, we can conceive of the PCT patent application as a quality-adjusted measure that can be used when we compare R&D performance across countries. As Figure 8 indicates, China is likely to overtake the first-place U.S. soon. The U.S. made 56,142 PCT applications and China 53,345 in 2018. During 2013-2018, the average PCT application growth rate was -0.35 percent for the U.S. and 20.52 percent for China. In innovation capability, we can clearly see the rise of China with its national economic growth.

China's Innovation Productivity

Model

It is problematic, however, to evaluate China's innovation capability by just comparing the number of R&D researchers, the amount of R&D expenditures, or the number of patent applications with other countries. R&D capabilities can be divided into two main categories: input and output. R&D input includes the number of R&D researchers and the amount of R&D expenditures. R&D output includes the number of patents or the number of science and technology articles published. When discussing China's innovation capability, many experts tend to just focus on the R&D input or the R&D output as described in the previous section. Advocates of increased R&D spending, or researchers, rarely explain how such inputs are related to outputs.

In my view, however, it is more meaningful to analyze the link between the R&D input and R&D output, namely innovation productivity, when we conduct comparative studies on national technological rise. In reality, one country can produce more R&D output with a relatively smaller amount of inputs than another country that spends a larger amount on inputs. Also, one country can produce more output than others by devoting an inefficiently large amount of resources. Therefore, I analyze innovation productivity in this section, setting up a simple theoretical model to assess China's innovative capability and compare it with that of three major economies: the U.S., Japan, and Korea.

An enormous amount of work has been done in economics to elucidate the relationship between output *(GDP)*, capital *(K),* labor *(L),* and the total factor productivity *(A)* that describes the influence of innovation on GDP growth.

$$GDP = A \cdot \mathrm{f}(K, L) \tag{1}$$

This relationship is relevant to understanding the trends in innovation and output for nations. Making some adjustments to this simple model, I examine the relationship between R&D output and R&D input and innovation productivity. To understand China's technological innovation productivity, I construct:

$$Patent = A_{R\&D} \cdot \mathrm{f}(N_{R\&D}, E_{R\&D}). \tag{2}$$

Specifically, I assume each country's patent production function in year t takes the form of Cobb-Douglas production function:

$$\begin{aligned} Patent_t &= A_t \cdot N_t^{\alpha} \cdot E_t^{\beta} \\ &= (\gamma + \epsilon_t) \cdot N_t^{\alpha} \cdot E_t^{\beta}. \end{aligned} \tag{3}$$

In year t, Each country's number of international patent applications (*Patentt*) depends positively on the number of R&D researchers (N_t), the amount of R&D spending (E_t), and technological innovation productivity (A_t), which consists of each country's fundamental or time-invariant technological capability (γ) and the year-specific unobserved characteristics (E_t). Since it is natural to think the number of R&D researchers and the amount of R&D expenditures are positively related to the number of international patents, I assume that each input's elasticity of patent production α and β are both greater than zero ($\alpha>0,\beta>0$). However, I assume that the marginal product of each input is decreasing ($0<\alpha<1,0<\beta<1$). In sum, the set of parameters to estimate includes:

$$\theta = (\alpha, \beta, \gamma, \sigma^2).$$

σ^2 is the variance of the error term ϵ_t. I assume that error terms are independent and identically distributed following normal distribution:

$$\epsilon_t \sim iidN(0, \sigma^2).$$

The set of data for each country (n=KOR, CHN, JPN, USA. The country subscript n is suppressed) is:

$$\{N_t, E_t, Patent_t\}$$

Regarding the time period t, I use monthly data from December 2000 to December 2017, which give me a total of 205 observations for each country.[10] I use the number of R&D researchers (N_t) and the amount of R&D expenditures (E_t) which are reported in the World Bank's World Development Indicators data set. For the number of PCT patent applications ($Patent_t$), I use the World Intellectual Property Organization (WIPO) IP statistics data. Here I assume that the number of PCT patent applications is a quality-adjusted measure of innovative outcomes. Focusing on the PCT system simplifies international quality comparisons for a couple of reasons. First, selection bias is avoided as, irrespective of the applicant's home country, PCT filings are always pursuing international protection. Second, the PCT system provides a unified procedure for filing patent applications in each of its contracting states.

First, to estimate the set of parameters (θ), I take natural log to the Equation (3):

$$\ln(Patent_t) = \ln(\gamma + \epsilon_t) + \alpha \ln(N_t) + \beta \ln(E_t).$$

From Equation (4), I can derive the equation of as a function of parameters and variables as:

$$\epsilon_t = \exp\{\ln(Patent_t) - \alpha \ln(N_t) - \beta \ln(E_t)\} - \gamma.$$

Using Equation (5), I can estimate the set of parameters that maximize the probability of observing the particular error terms linked to particular variables (N_t, E_t , $Patent_t$). Based on this model, I compute each year's likelihood contribution to form the log-likelihood function as $LL(\theta)$:

$$LL(\theta) = \sum_{t=1}^{205} \ln(P_t).$$

P_t represents the probability density of observing the dependent variables:

$$P_t = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{\epsilon_t^2}{2\sigma^2}\right].$$

After estimating $\theta=(\alpha,\beta,\gamma,\sigma^2)$ that maximized $LL(\theta)$, I calculate A_t, which is the innovation productivity of each country in year t, by calculating the sum γ of and ϵ_t.

Empirical Results

Table 2 presents the estimation results of the parameters. It suggests the following.

First, it is interesting to see that all four economies exhibit constant returns to scale ($\alpha+\beta=1$). However, each country has different R&D spending and researchers' shares of output. China and Japan are more labor-intensive in producing PCT ($\alpha>\beta$). It is a better strategy for them to input more R&D researchers than R&D spending to produce international patents. By contrast, Korea and the U.S. are more capital-intensive in producing PCT ($\alpha>\beta$). For them, it is a superior strategy to incur more R&D expenditures than to hire more R&D researchers to produce international patents.

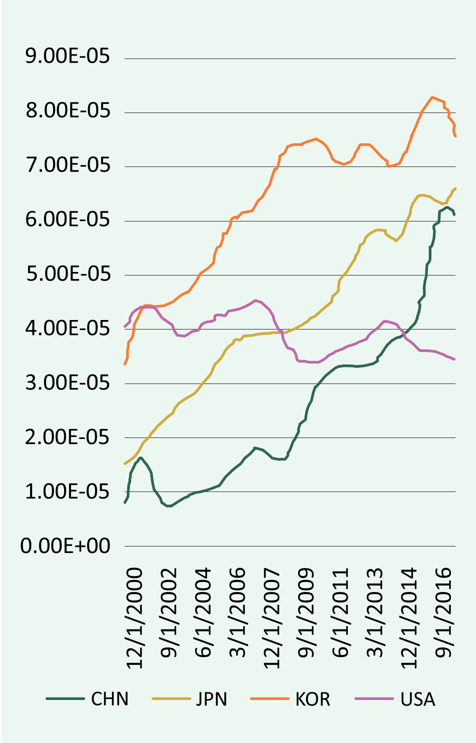
Table 2. Estimates of Model

	Labor Elasticity of Innovation Production (α)	Capital Elasticity of Innovation Production (β)	Fundamental Innovation Productivity (γ)
China	0.528**	0.492**	2.46e-05**
Japan	0.533**	0.514**	4.14e-05**
Korea	0.487**	0.517**	6.41e-05**
US	0.496**	0.526**	3.89e-05**

Note: *p<0.1; **p<0.05.
Source: Author's estimation

Second, in terms of fundamental (time-invariant) innovation capability during 2000-2017, Korea has the highest productivity (γ=6.41e-05), followed by Japan (4.14e-05), the U.S. (3.89e-05), and China (2.46e-05). This indicates that relative to its smaller number of researchers and spending, Korea has produced more PCT patents than other countries (Figure 8). Although the U.S. and China are making the most and second-most PCT applications in recent years, Korea has been the most efficient in producing international patents.

Figure 9. Innovation Productivity (A_t)



Source: Author's calculation

Figure 10. Innovation Productivity (A_t) Index (Korea=100%)

Source: Author's calculation

Figure 9 and Figure 10 provide a clear picture of the innovation productivity of China and the other three countries, beyond Table 2. Figure 9 calculates the innovation productivity (A_t) of each country from December 2000 to December 2017, and Figure 10 provides the innovation productivity of each country relative to that of Korea (Index, Korea=100%). Considering innovation productivity, we can observe the following.

We can observe that the innovation efficiency of Korea steadily increased entering the 21st century, although it stalled a little after the global financial crisis. Similarly, that of Japan steadily increased entering the century. Since the global financial crisis in 2008, China has rapidly increased its innovation productivity. However, the innovation productivity of the U.S. stagnated during the same period. The empirical results indicate that China's innovation productivity has surpassed that of the U.S. since the latter half of 2014, and recently it even threatened Japan's position. Figure 10 shows that China's innovation productivity is increasing more rapidly than that of Korea, suggesting Korea has reason to be concerned by its relatively low rate of increase in innovation productivity. Considering its fast pace, the innovation productivity of China is likely to soon exceed that of Korea.

South Korea's Concern: Semiconductors

If we examine the top 10 most exported products of Korea (Table 3) and those of China in 2019 (Table 4), we can easily find five items that appear to overlap: memories (HS 854232),[11] petroleum products (HS 271019), electronic integrated circuits (ICs, HS 854231),[12] parts for telephone sets (HS 851770), and parts for computers (HS 847330). This suggests that the economic relationship between Korea and China has significantly shifted to an intra-industry division or competition.

Table 3. South Korea's Top 10 Exports, 2019

Rank	HS 6-digit	Products	Amount (Billion$)	Share of Total Exports (%)
1	854232	Memories	53.2	9.8%
2	271019	Other, Petroleum products	29.8	5.5%
3	854231	Electronic integrated circuits	20.7	3.8%
4	870323	Motor cars	19.7	3.6%
5	890120	Tankers	12.4	2.3%
6	851770	Parts for telephone sets	12.2	2.2%
7	847330	Parts and accessories for Automatic data processing machines (computer)	11.3	2.1%
8	852990	Other electrical equipment and parts (radar, transmission, radio-broadcast apparatus)	10.0	1.9%
9	271012	Light oils and preparations	9.5	1.8%
10	870899	Other, Parts and accessories for motor vehicles	8.7	1.6%

Source: Korea International Trade Association, K-Statistics

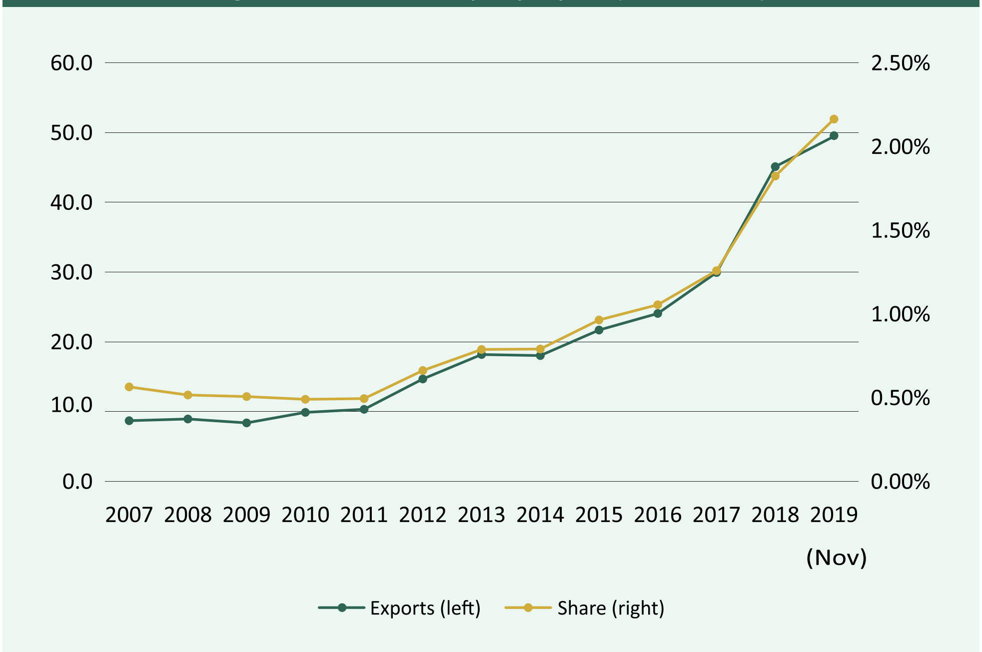
Table 4. China's Top 10 Exports, 2019

Rank	HS 6-digit	Products	Amount (Billion$)	Share of Total Exports (%)
1	851712	Telephones for cellular networks or for other wireless networks	113.2	5.0%
2	847130	Portable digital automatic data processing machines (laptop computers)	87.8	3.9%
3	854232	Memories	48.2	2.1%
4	851770	Parts of telephone sets	43.7	1.9%
5	851762	Machines for the reception, conversion & transmission or regeneration of voice, images or other data, including switching & routing apparatus	42.1	1.9%
6	854231	Electronic integrated circuits	32.0	1.4%
7	950300	Tricycles, scooters, pedal cars & similar wheeled toys, dolls, other toys, puzzles of all kinds.	28.8	1.3%
8	847330	Parts and accessories for Automatic data processing machines (computer)	28.6	1.3%
9	271019	Other, Petroleum products	26.0	1.1%
10	854140	Photosensitive semiconductor devices, light emitting diodes	21.9	1.0%

Source: General Administration of Customs People's Republic of China, China Customs Statistics

Among these five products, semiconductors (memories and electronic ICs) are significantly important for the South Korean economy since not only are memory chips the top export item, but also semiconductors account for almost 14 percent of total exports. Thus, China's technological advancement in the semiconductor industry is a great concern for South Korea. In terms of productivity, China is not yet a strong competitor to South Korea in the semiconductor market. Even though the competitiveness of Chinese semiconductor vendors has improved greatly in recent years (Figure 11), the industry still relies heavily on key components from other countries, resulting in a self-sufficiency rate of less than 20 percent.[13] However, the Chinese government's recent ambitious policies and the huge amount of total investments worry Seoul. South Koreans already observed the withering of their liquid crystal display (LCD) industry due to Chinese companies' offensive low-cost supply backed by massive support from the Chinese government.

Figure 11. China's Memory Chip Exports (Billion US$, %)



Source: Korea International Trade Association, K-Statistics
Note: Memories (HS 6-digit 854232) includes DRAM, SRAM, Flash memory and other memory ICs.

The Chinese government has been implementing various measures to end the country's dependence on foreign production in key sectors. In particular, China is pursuing a plan to produce semiconductors on its own without relying on the U.S. and Korea. At the heart of its goals, the "Made in China 2025" sought to raise the domestic content of core components and materials, including IC chips, to 40 percent by 2020 and to 70 percent by 2025. In 2015, the Chinese government announced that it would invest $161 billion over the next 10 years to localize semiconductors.[14] Accordingly, "National Integrated Circuit Industry Investment Fund Phase I Co., Ltd.," often referred to as the "National Big Fund Phase I," was established, and invested $19.6 billion in the semiconductor industry, making it the largest investment fund in China. National Big Fund Phase I funded about 80 semiconductor projects and 55 semiconductor companies. In October 2019, the Chinese government announced the second phase of the project, the "National Big Fund Phase II," which will invest $28.9 billion in the industry. This second-stage national semiconductor fund is planning to carry out everything related to semiconductors from designing to manufacturing, assembling, and inspection in China.[15]

China's Motivations

There are multiple reasons why China is eager to secure the sovereignty of the semiconductors. First, China is concerned about the trade deficit incurred by importing semiconductors. Currently, China consumes more than 50 percent of global semiconductors, and about 90 percent of China's semiconductor consumption is supplied by foreign companies.[16]

Second, semiconductors are essential to power most fast-growing technologies such as 5G, artificial intelligence (AI), Internet of Things (IoT) and autonomous driving. In China, the state and domestic manufacturers are working closely together to develop a socialist market economy by utilizing enormous capital and a huge domestic market. China has not been successful in developing the semiconductor manufacturing industry in recent decades, but it may succeed this time because of demand expansion and technological innovation from the Fourth Industrial Revolution. In particular, the semiconductor industry is expected to grow robustly as the utilization of semiconductors increases in the emerging sectors such as IoT, 5G, AI, and autonomous driving. Recently semiconductor companies are increasing their investment in R&D. According to IC Insight, the global R&D expenditure of the semiconductor industry in 2018 was $64 billion.[17] Moreover, worldwide semiconductor sales increased 38.2 percent from $339 billion in 2016 to $468.8 billion in 2018, while sales increased only 13.6 percent from $298 billion in 2010 to $339 billion in 2016.[18]

Third, the U.S.-China trade conflicts push China to accelerate development of its own semiconductor industry. Since 2018, the U.S. has imposed additional tariffs on imported goods from China due to its unfair trade practices, its infringement of intellectual property rights, and protection of U.S. industries and national security. Recently, the U.S. government has issued strong regulations, such as sanctioning transactions with Chinese tech companies such as Huawei and ZTE and strengthening visa review. Such tensions between the U.S. and China are also becoming fierce over semiconductor hegemony. Whenever the Chinese government attempts to merge and acquire (M&A) American companies through semiconductor funds, the U.S. government blocks it. In 2015, Tsinghua Unigroup in China tried to acquire Micron, the world's third-largest DRAM company, for $23 billion and failed because it was disallowed by the Committee on Foreign Investment in the U.S. (CFIUS). In 2016, Tsinghua Unigroup also pursued the acquisition of SanDisk but it had to withdraw from the negotiating table when the U.S. authorities announced it would investigate the deal.

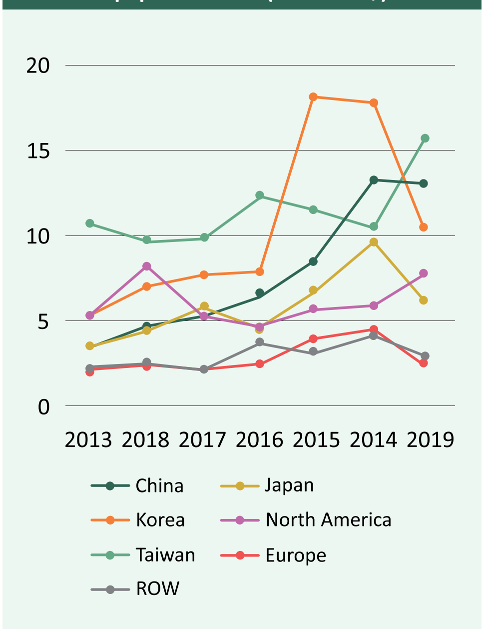
Current Capability

The industry estimates that China has little lag to catch up with South Korea's semiconductor technology. Regarding memory chip manufacturing, China has launched three active units: Yangtze Memory Technologies Co. (YMTC) for flash memories, ChangXin Memory Technologies (CXMT) for mobile device DRAMs, and Jinhua Integrated Circuit (JHICC) for entry-level DRAMs. The three companies alone have invested more than $37.5 billion so far.[19] Experts expect there is a five-year lag in DRAM manufacturing technology between

South Korea and China.[20] Also, the Chinese investment bank China Renaissance estimated that China is four years behind Korea in System IC manufacturing.[21] However, with the full support of the Chinese government, the technological gap between Korea and China is rapidly narrowing. In September 2019, YMTC started mass producing China's first 64-layer 3D NAND flash memory chips. Moreover, according to TechWeb, an IT media in China, CXMT recently announced that it officially began to sell DRAM memory. CXMT is the first Chinese company to mass-produce and sell DRAM. A couple of years ago, Tsinghua Unigroup announced it had a plan to mass-produce DRAMs, but there has never been a real product on the market. Although much remains to be done, China could become a global semiconductor powerhouse that threatens Korea and Taiwan soon.

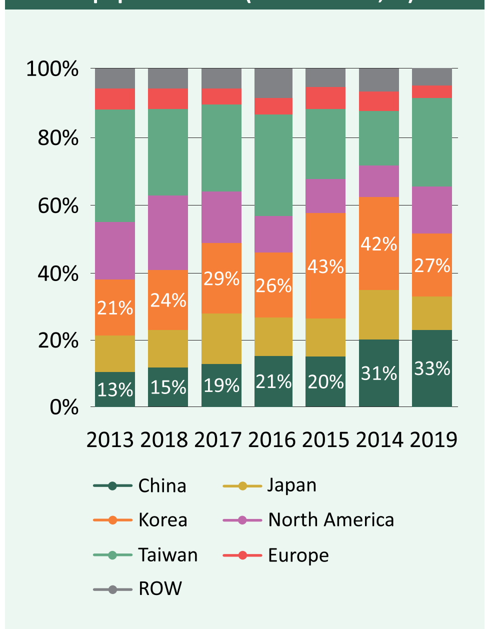
Another way to conjecture the potential for future growth is by examining the semiconductor manufacturing equipment market. According to the International Semiconductor Equipment and Materials Association (SEMI), last year, China's semiconductor equipment investment amounted to $12.9 billion, surpassing Korea's $10.5 billion (Figure 12 and Figure 13). Before 2019, Korea was never outpaced by China in terms of investing in semiconductor equipment.

Figure 12. Global Semiconductor Equipment Sales (Billion US$)



Source: SEMI, "Global Semiconductor Sales Forecast," 2017, 2018, 2019.

Figure 13. Global Semiconductor Equipment Sales (Global Share, %)



Source: SEMI, "Global Semiconductor Sales Forecast," 2017, 2018, 2019.

Given that the Korean semiconductor industry currently dominates 75 percent of the global DRAM market and 50 percent of the global NAND flash memory market, mass production of DRAM and flash memory by Chinese semiconductor companies is a threat to the South Korean economy. In the early stage, due to the technological gap, China is expected to increase its share little by little, focusing on low- and medium-end products used in domestic consumer products, making the most of the advantage of being the largest semiconductor market in the world. China will improve the technical level of designing and manufacturing by meeting domestic demand. The U.S.-China trade tensions will also induce Chinese mid-end smartphone makers such as OPPO and Vivo to replace their memory chip suppliers from foreign firms to domestic firms. It will not happen right away, but if China replaces all of its DRAM imports from Korea with domestic products, Korea's annual semiconductor exports will decrease by 19.2 percent. If China replaces all Korean DRAMs and flash memories with its own, Korea's annual semiconductor exports will fall 25.6 percent. Furthermore, if we assume South Korea has to compete in the global market against China, the number will drop even further.

Conclusion

The future of the Korea-China economic relationship could not be explained without considering the advent of the Fourth Industrial Revolution and the technological development of China. This paper presents evidence that supports China's technological rise. Total R&D expenditures, R&D researchers, and the number of international patents are the indicators most frequently cited. Although not yet having reached the U.S. levels, China's total R&D expenditures and PCT patent applications are increasing more rapidly than those of the U.S. and are likely to outpace all countries in the near future. China already has the largest number of R&D researchers and real GDP in the world.

Besides the aforementioned indicators, this chapter provides an important first step towards building an understanding of China's innovation productivity, which I find has rapidly increased since the global financial crisis. This is in line with the recently implemented Chinese government's ambitious measures. China announced "Made in China 2025" in 2015 to improve existing manufacturing and to foster cutting-edge industries. "Made in China 2025" is intended to advance China's manufacturing industry in three stages over 30 years. The first stage (2015-2025) targets entering the group of global manufacturing powerhouses that includes the U.S., Germany, Japan, and Korea. The second stage (2026-2035) aims to secure middle-ranking among the powerhouses, and the third stage (2036-2045) plans to put China at the top of the manufacturing powerhouses. "Made in China 2025" particularly emphasizes 10 key technology industries that are closely related to the Fourth Industrial Revolution, including next-generation information technology (IT), aerospace, high-tech ships, advanced rail transit equipment, smart vehicles, agricultural machinery, new materials, biopharmaceuticals, and robotics.

Currently, China has a much lower tertiary enrollment rate than the advanced countries. Accordingly, institutions of higher education perform only a small portion of China's R&D, averaging just 9.3 percent between 1991 and 2016. This is significantly less than in Japan (13.5 percent) and Germany (17.3 percent).[22] However, we can also conclude that if China fully develops academic R&D capacity with its newly initiated "Education 2035," it would be able to explosively boost its innovation capabilities.

The empirical results of this research show that China's innovation productivity is still around 80 percent of Korea's but it is increasing more rapidly. Furthermore, as illustrated in Figure 10, if Korea has reason to be concerned with this trend, the U.S. should have even greater concern. This is why we are observing the U.S.-China trade tensions and technology rivalry these days. Ironically, increasing pressure from the U.S. is expected to accelerate

China's domestic-market-oriented growth strategy, strengthen its R&D capabilities in advanced technology, enhance its own competitiveness in emerging industries, and expand its overseas investments.

With the onset of the Fourth Industrial Revolution, China is rapidly closing the quality gap and technology gap in the major industries in which Korea has a comparative advantage. Recently, Korea has been seriously concerned about the decline in competitiveness of its key industries including the semiconductor industry, as China rises. Some research asserts that China is even ahead of Korea in emerging industries such as artificial intelligence, robotics, machine learning, and aerospace equipment. As Korea and China both face the Fourth Industrial Revolution, they are expected to intensify competition to secure technological advantages and make their voices heard in international standard-setting in these new industries. If Korea does not adequately respond to changes, it may be difficult to maintain a comparative advantage over China. Korea should consider various countermeasures such as whether to go head-to-head in global market share, to collaborate in a horizontal division of labor, or to cooperate through equity participation.

Whether Korea decides to go head-to-head with China or cooperate with China, in any case, it urgently needs to secure its technological competitiveness through expanding R&D investment, intensifying innovation productivity, and supplying core technologies. Given the characteristics of fast-developing high-tech industries, demand for cooperation in technology and human resources is likely to increase between Korea and China. However, the cooperative partnership between the two will only be guaranteed when Korea maintains global competitiveness in innovation capacity.

Endnotes

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[10] World Development Indicators' R&D data set and WIPO's PCT data set report only yearly data; so I used the spline interpolation method to make the sample monthly, which gave me a much bigger sample size for the analysis. Spline interpolation is a form of interpolation where the interpolant is a special type of piecewise polynomial called a spline. Spline interpolation is often preferred over polynomial interpolation because the interpolation error can be made small even when using low-degree polynomials for the spline. Spline interpolation avoids the problem of Runge's phenomenon, in which oscillation can occur between points when interpolating using high-degree polynomials.

[11] HS 854232 includes DRAM (dynamic random access memory), SRAM (static random access memory), and flash memory.

[12] HS 854231 includes monolithic integrated circuits, hybrid integrated circuits, and multichip integrated circuits.

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