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# Strategic Choices in Science and Technology

Korea in the Era of a Rising China

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## Summary

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### China—Opportunity or Threat?

China has become the biggest recipient of foreign direct investment in the world. It is the largest trading country in Northeast Asia, surpassing even Japan, and a major export market for many Asian economies including Korea, Japan, and Taiwan. As China's economy becomes more powerful, many see it as presenting a formidable threat as well as an opportunity. Koreans are no exception in having these mixed feelings toward China. Even if we confine our interest to the economic arena, Korea's list of potential threats from China is considerable: the hollowing out of the manufacturing sector, job loss, and loss of shares of the world market and the China market.

The effect of China's economic rise on the Korean economy has been significant. China is now Korea's largest trading partner and the largest destination for Korea's foreign direct investment. As Korea's economic relationship with China continues to develop, economic threats and shocks emanating from China could be as significant as China's positive effects on Korean economy.

Active investment in China, finding more market opportunities in China, and strengthening the cooperative relationship with China have so far been desirable paths for Korean companies and governments to take. However, what should Korea do to ensure the prosperity of its economy and to better face uncertainty in the future?

What would be appropriate strategies and policies for Korea to pursue, particularly in science and technology (S&T)?

In this context, the Korea Ministry of Science and Technology (KMOST) asked RAND through the Korea Institute of Science and Technology Evaluation and Planning (KISTEP) to assess the benefits and risks of Korea's economic engagement with China and to draw policy implications for Korea, focusing in particular on the science and technology progress of both countries.

## **Objective, Approach, and Structure of the Study**

This study identifies Korea's main economic concerns related to China's rapid industrial development and growing S&T capabilities. Its aim is to show alternative S&T strategies that Korea may follow and how those strategies may affect Korea's economic prosperity.

Using trade, investment, and research and development (R&D) data, we analyze the general economic relationship between Korea and China at the industry as well as the aggregate level to uncover general trends and the macro configuration of the technological capabilities of both countries. Next, we analyze the main drivers of change in China's S&T progress, compared with those of Korea, in the framework of China's national innovation system. Micro-level analyses of China's institutional arrangements, the relative strengths of its R&D performers—industry, university, and research institutes—and its national strategies and programs complement the macro-level analysis.

Based on both macro data analysis and micro-level examination of institutional structure and resource allocation, we develop a simple model of the Korean economy and alternative S&T strategies that Korea could follow. We then show how those strategies affect Korean prosperity, explicitly considering the uncertainties that Korea will confront. The model captures key elements of our concern, such as the technology gap between the two countries, international competitiveness, and such external shocks as a possible change in China's macroeconomic performance. In our future scenario, we introduce an

approach that minimizes the maximum “regret” associated with pursuit of one or another of the strategies. *Regret* is defined as the difference between the result of a chosen strategy in a specified state of the world and the result that would have been obtained if the optimal strategy for those circumstances had been pursued.

### **Korea’s Main Economic Concerns About a Rising China**

So far, Korea has enjoyed the opportunities provided by China’s growing markets. Korea’s major export products to China are intermediate goods, such as core components and equipment, and Korea’s exports have grown along with China’s economy and exports. However, it is uncertain whether this positive relationship between Korea and China can be sustained in the long run.

Even though equipment and components comprise Korea’s major export items to China, Korea does not have a comparative advantage in those items. Korea actually imports core components and high-tech equipments from Japan and other industrialized countries. In fact, this has been the main source of Korea’s trade deficit with Japan, which is larger than its deficit with its other trading partners. Industrialized countries such as the United States and Japan are the dominant players in production of core components and equipment.

While Korea has found a niche in the Chinese market in terms of price competitiveness, this niche may be harder to maintain as competition in the Chinese component and equipment market increases. A combination of advanced technologies from the world’s leading companies and China’s cheap and disciplined labor may create new markets in China and remove Korea from the market niche it now enjoys.

The competitive pressure from China may have been relatively weak since the 1990s because the world economy has been booming with a strong U.S. economy and the explosive growth of China. But in the event of a worldwide recession—because of an economic downturn in China, high oil prices, or other reasons—the once-positive relationship between Korea and China could easily become

negative. In addition, whether China can successfully slow down its overheated economy and sustain its potential growth path is still a matter of controversy.

What would be an appropriate strategy for Korea to pursue to maintain its economic dynamism in light of these uncertainties? Is Korea moving in the right direction to ensure a prosperous future? Among many factors, answers to these questions will depend on whether Korea can maintain its technological leadership, at least in selected areas of products and technologies.

## **S&T Indicators and Trends**

### **In Terms of Aggregate S&T Capability Indices, Korea Is Ahead of China**

The Technological Achievement Index (TAI) of the United Nations Development Programme (UNDP), the ArCo Index, and RAND's Science and Technological Capacity Index (STCI) all show that Korea's aggregate S&T capacity is higher than that of China. According to STCI, Korea is in the second-tier group and ranks 18th out of 76 countries (see Table 3.1 in Chapter Three). According to the TAI and ArCo index, Korea is in the top group in S&T capability and ranks 5th and 19th out of 72 and 172 countries, respectively, while China is to the third group and ranks 45th and 85th, respectively.

The rankings on the aggregate S&T capacity indices, however, must be interpreted carefully. Many individual indicators used in constructing the aggregate capacity indices were standardized by size of population or GDP. Therefore, China's lower ranking on the TAI, ArCo, and STCI indices, in comparison with Korea's, does not necessarily mean that China's absolute S&T capability or potential is inferior to Korea's.

### **China Is Ahead of Korea in Absolute Scale of R&D Investment and Human Resources**

While Korea's R&D intensity is more than twice as high as that of China, the absolute level of China's R&D expenditure of China is 10

percent higher than that of Korea. If purchasing power parity (PPP) is used as a measure, China's R&D expenditure is three times as great as that of Korea. The number of scientists and engineers per 10,000 population in Korea is 2.5 times that of China, whereas the absolute number of full-time equivalent scientists and engineers of China is seven times that of Korea. China's large and increasing number of S&T personnel gives it an obvious advantage in human resources. China currently ranks second in the world in number of R&D personnel. It has more doctoral degree holders than Japan, and the number of Chinese who have completed higher education in the S&T field is close to that of the United States. China's full-time equivalent R&D personnel was over 1 million in 2002, second only to that of the United States and roughly six times that of Korea.

### **China Has a Strong Research Capability in Basic Science**

Investment in basic research is often used as a proxy for future-oriented research activities and long-term innovation capabilities. In China, less than 6 percent of total R&D funding is allocated to basic research, which amounts to half of Korea's basic research investment. However, China publishes twice as many scientific papers as Korea does.

According to the world ranking of ISI Essential Science Indicators covering the ten-year period between 1993 and 2003, China ranked 9th and Korea ranked 16th, based on the number of scientific papers in all fields catalogued by the Science Citation Index (SCI). In terms of total number of citations, China ranked 19th whereas Korea was not in the top 20 during the period. China's rate of research paper publication is also rising much faster than Korea's. Although some say that a majority of China's researchers are not yet world-class thinkers and that Chinese R&D results are not as influential as those of the world's leading researchers, China has made consistent and rapid progress in recent years—not just in the quantity but also in the quality of papers published.

Why does China's scientific paper publication outperform its investment in basic research? One of the reasons is that China has abundant human resources for R&D in universities and research in-

stitutes—resources that can be tapped for marginal or sometimes no extra funding. Graduate students often serve as low-cost researchers, and there were more than 500,000 graduate students enrolled in China in 2002—nearly twice as many as in Korea. Another reason may lie in the difference in accumulated knowledge stock in basic science. Like other socialist countries, China has emphasized the importance of “big sciences” such as aerospace, nuclear science, oceanography, and other basic sciences; even now, this tradition continues to some extent in the context of national security.

### **Patent Data Show That China Has Limited Invention Capabilities**

The number of patent applications in China and U.S. patent awards to Chinese nationals suggests that China is still a country with relatively low capabilities in invention and innovation. In 2002, Chinese citizens accounted for only 19.4 percent of invention-type patents in China. In 2003, China’s share of foreign patent applications in the United States was only 0.1 percent. In contrast, Japan’s was 43.8 percent, Taiwan’s was 6.5 percent, and Korea’s was 4.9 percent.

Another salient feature is that the industrial sector is not the major player in invention-type patents in China. Chinese universities, research institutes, and government together held twice as many valid invention-type patents as industry at the end of 2001. This contrasts sharply with foreign patenting activities in China, where the lion’s share of valid invention patents are owned by enterprises.

The Technology Review’s (TR’s) Annual Patent Scorecard ranks the U.S. patent portfolios of 150 top technology companies in eight industries including aerospace, computers, electronics, semiconductors, telecommunications, biotechnology and pharmaceuticals, chemicals, and automotive. These data provide not only the patent counts for each company but also other indices based on frequency of citation of the patents and links to scientific research. No Chinese company was listed on the TR Patent Scorecard as of 2003, whereas twelve Korean companies are listed.

Of course, patents statistics are only one of several indicators of innovation capability. Technology assimilation capability and the linkage of technology to the global R&D network may be as impor-

tant as invention capability in China since its economy is still in the development stage.

## **China's National Innovation System and R&D Strategies**

To understand China's S&T capabilities and its future potential, we must understand its underlying and stated national goals and objectives. China's S&T capabilities are built on and enhanced by national strategies, policies, and plans. These are implemented by means of complex institutional arrangements and various R&D projects, augmented by the development of S&T human resources and boosted by foreign direct investment (FDI) inflows and outflows, as well as international cooperation and exchange.

### **S&T and Education Are the Two Pillars of Economic Development in China; Openness Is a Major Strategy**

In 2002, the Chinese government set an ambitious long-term goal to quadruple its GDP to US \$4 trillion with a per capita GDP of \$3,000 by the year 2020. The government plans to achieve this goal by “taking a new road to industrialization by implementing the strategy of rejuvenating the nation through science and education and that of sustainable development.”

Jiang Zhemín's Report to the 16th CPC Party Congress in 2002 set out the guidelines for implementing the strategy of “rejuvenating the nation through science and education.” It also emphasized that economic development was not to be isolated but should be increasingly open to the outside world in order to “actively participate in international economic and technological cooperation as well as competition.”

From the strategy and the guidelines, we clearly observe that openness is important to China and that S&T progress and education are the two main pillars of its future economic prosperity.

### **Universities Are Major Knowledge Creators in China**

Universities are the major players in Chinese research—not only basic science but also applied research and commercialization. In 2002, universities accounted for 77 percent of Chinese science and engineering papers in international publications.

Universities in China also provide a strong R&D base for applied research and commercialization. By the end of 2002, 105 National Key Laboratories (i.e., more than two-thirds of the total key labs), 43 National Engineering Centers, 22 science and technology parks, and six technology transfer centers were affiliated with Chinese universities.

Beijing University and Tsinghua University are especially prominent in breeding high-tech spin-offs. Qinghua Tongfang and Beijing University's Founder's Group are good examples of spin-offs. These companies have grown big enough to leave the universities. But although they are listed on stock exchanges and have their own headquarters, the universities are still their main shareholders.

On the other hand, the fact that China's major R&D capability is concentrated in sectors other than industry may slow down growth in innovation capability. This is because industry responds to market incentives more effectively than do universities and government research institutes.

### **China's Indigenous Industrial Sector Is a Relatively Weak Link in Its National Innovation System**

Industry is the main innovator in most Organization of Economic Cooperation and Development (OECD) countries including Korea. In China, however, universities and government research institutes and laboratories are the main R&D performers. China's industrial sector in general has yet to improve its innovation capability to the point of becoming a leader in the country or the world.

The Chinese industrial sector depends heavily on foreign technology sources. Almost 90 percent of China's high-tech exports consist of processed goods that use imported or foreign-supplied materials. Considering China's record-breaking economic growth, it was probably a better strategy for Chinese companies to adopt readily

available technologies instead of innovating on their own, which takes much more time than purchasing the technologies. A similar phenomenon was observed in Korea at an earlier stage of its development.

Of course, there are many prominent high-tech companies in China. However, compared with global technology leaders, they are still small and weak in the areas of sales and intellectual property rights. For example, Huawei is an exemplary high-tech company that has achieved great success in global marketing and technological progress. It attracted global attention when it was involved in an intellectual property rights dispute with Cisco Systems, the world's largest maker of routers and switches that transmit data and direct Internet traffic. However, Huawei's R&D expenditure in 2003 was only 13 percent of that of Korea's Samsung Electronics. Huawei's total sales amounted to about 11 percent of Samsung's in the same year.

Many large-scale state-owned companies in China are listed among *Fortune* magazine's global top 500 companies. However, they are basically in traditional industries, such as banking, insurance, energy, manufacturing, and utilities.

### **Interaction with the Foreign Sector Has Contributed Significantly to China's Economic and Technological Progress**

Foreign direct investment in China has contributed significantly to its rapid economic development. An International Monetary Fund (IMF) study showed that FDI in China has contributed nearly 3 percent to China's annual GDP growth during the 1990s. In other words, FDI explains almost a third of China's GDP growth rate while its share of total fixed asset investment averaged only 12.5 percent between 1993 and 2002.

By the end of 2002, the number of employees in foreign-invested enterprises (FIEs) had reached 23.5 million, accounting for 11 percent of China's urban workforce. FIEs have conducted extensive training of Chinese employees to enable them to use the advanced technologies supplied by the FIEs and to operate within their advanced management systems. In 2002, FIEs accounted for 33.4

percent of China's industrial output, 52.2 percent of its total export, and 21 percent of its tax revenue.

Interaction with the foreign sector has contributed significantly to the rise of high-tech industries in China. Chinese electronics and telecommunication equipment manufacturers, such as Huawei, Zhongxing, TCL, and Haier, are good examples of how the massive inflow of FDI has enabled Chinese indigenous companies to become serious competitors with incumbent foreign firms. Huawei, for instance, started out selling foreign-made telecom switches and then became a globally competitive producer of switches and routers.

### **Evaluation of China's NIS and Strategic Direction**

China's strategic strength lies mainly in its openness as an engine of growth, its strong bargaining power due to its huge domestic market, and its abundance of highly educated people. China's vulnerability lies in the fact that its major R&D capability is concentrated in sectors other than industry, which may slow down innovation.

This weakness is in part inherited from China's tradition of government-led technology push in S&T development during the era of the Cold War and the communist economic system. Because of this very weakness in "demand pull" factors due to its relatively weak industrial R&D capability, the Chinese government again has tended to entrust most of the national R&D programs to R&D institutes and universities. However, this strategy may risk further weakening the link between R&D bodies and market incentives as well as the innovation capability of China's industrial enterprises.

It may take a considerable time for China's national innovation system to become as efficient as those of advanced countries.

China's enormous and fast-growing domestic market is a great asset that can leverage the nation's economic development and S&T progress. Because of this huge market, China has been able to attract more FDI and more multinational corporation (MNC) R&D centers, bargain for more technology transfer, produce abundant high-quality scientists and engineers, and even pursue its own technology standard.

Not only manufacturing but also R&D activities are attracted to China's large market and abundant human resources. According to a survey by *The Economist* magazine, China has become the top destination for overseas R&D by multinational corporations, despite its poor protection of intellectual property rights. Some studies already assert that China is not only the manufacturing powerhouse of the world but also a research powerhouse. China is making rapid progress in S&T, with a solid conceptual framework, a focused strategy, and a favorable infrastructure and economic environment.

## Options for Korea

The limited size of Korea's domestic market, always one of its weaknesses, has driven Korea to pursue an export-oriented development strategy. With the rise of China, however, Korea's outward-looking strategy, which is based on selling manufactured commodities to the world, may be less effective than before. Unless Korean companies sell goods with better technological content and higher value-added than Chinese companies, Chinese companies will be in a better position to produce most manufactured goods.

What can Korea do to ensure its prosperity in the future? Korea does not have the depth of knowledge in basic science or generic technologies that Japan and the United States have. It is relatively capable in applied technology and commercialization, but this relative strength might not be sustainable as a long-term advantage because applied technologies and commercialization capability are more easily obtained than basic and generic technologies. Especially in China, progress in applied technology and commercialization could be much more rapid than in other developing countries because of such positive drivers as huge FDI, significant training and education by FIEs, and the establishment of R&D centers by MNCs.

### Support R&D Intensity but Obtain R&D Efficiency Too

High R&D intensity is one of Korea's strengths. However, Korea has a longstanding problem with relatively low R&D efficiency. Several

factors may contribute to this. As we will see in Chapter Three, although Korea is one of the most capable countries in terms of R&D-to-GDP ratio, the density of scientists and engineers in Korea is not as high as in other countries.

To support its intensive R&D activities, Korea will need more high-quality scientists and engineers. This, of course, cannot be achieved in the medium term. To correct this weakness, Korea must build networks with others in the “global brain pool.”

Another major determinant of R&D efficiency is the level of existing knowledge stock. If the knowledge stock is low, R&D investment flows do not produce as much as in countries with a high knowledge stock. R&D investment is a necessary condition to increase the knowledge stock itself. In other words, to reach a certain level of R&D efficiency, Korea must accumulate knowledge stock, and this in turn will need R&D investment.

### **Should Korea Be More Engaged in the China Market?**

Korea has the option to complement its weaknesses by tapping into China’s strengths. Abundant human resources for both production and R&D and a large and a fast-growing domestic market are China’s most salient strengths—strengths that Korea does not have. Such strategies as inducing foreign investors in China to source from Korea or finding complementary markets with China have been widely discussed in the existing literature in Korea.

In fact, Korea has been heading in this direction already by investing in China, producing in China, and conducting R&D in China. Proximity to China is another factor that has strengthened the economic relationship between Korea and China. As long as their economic environments are in harmony and the mutually beneficial economic relationship between the two countries is sustained, this would be a good bet for Korea. However, we are not sure what the net effect of greater engagement with China will be in the future.

Will Korea continue to enjoy opportunity in China? Could there be a “boomerang effect” from China? Could China carve out a portion of the world market and exclude Korea? There are no

straightforward answers to these questions, which are part of Korea's conflicting perceptions about China.

### **Education for Creative and Innovative Thinking**

Creative and innovative thinking is more than merely absorbing existing knowledge. Fostering true creativity will require educational reform at all levels—primary, secondary, and tertiary. First, Korea will need an adequate supply of highly educated and trained researchers to make further progress in S&T. As of 2003, the ratio of scientists and engineers to the total higher education degree holders in Korea was significantly higher than in the United States, Japan, and many other industrialized countries. However, the number of scientists and engineers per 10,000 people is lower in Korea than in other advanced countries, mainly because the general ratio of highly educated people to the total population is lower in Korea. Therefore, Korea must continue to support broader access to higher education. In addition, the quality of graduate-level education needs more attention. Compared to that of advanced countries, graduate-level education in Korea is quite underdeveloped, even though it has been improving recently. The Korean Ministry of Education and Human Resource Development has put a great deal of effort into its “BK 21” project to improve graduate education in the 21st century.

Labor unions in Korea are known to be highly confrontational. Developing a well-educated, versatile workforce that is able to conduct R&D and convert it to innovation could serve as a win-win solution to the current confrontational relationship between business and labor. Such an educational strategy could connect the knowledge-intensive industrial activities of the demand side with the more expensive (relative to China) but highly skilled labor force from the supply side. Ideally, Korea might want to aim for a society in which its citizens are paid as much as those with similar education and skills in advanced countries, instead of targeting a specific level of per capita income. To achieve this goal, however, both business and labor need to be more innovative so that Korea's labor productivity will be as high as that in advanced countries.

### **Openness May Have to Be Korea's Strategy No Less Than China's**

With “openness” as a growth engine, China has achieved explosive economic growth and impressive technological progress even though it is still a socialist country with a less sophisticated market system than some other developing countries. Few countries remain economically isolated since China opened its doors and other former socialist countries also made the transition to a market economy. However, in the eyes of foreign investors, Korea is still a hostile country for foreign investment. Many foreign business leaders think Korea is relatively isolated from active global networking.

Korea has not yet carved out a significant market in the internet or software business. In contrast, India takes over \$100 billion in business from global software outsourcing by 185 Fortune 500 companies, according to the UNDP (2001). Both India and China have strong links with Silicon Valley, and the further development of information technology will continue to enhance the ability of multinational corporations to tie together globally distributed laboratories and firms.

Korea is a small country with a limited domestic market and is less attractive to foreign investors than China, Hong Kong, or Singapore. Therefore, Korea must emphasize both looking outward to explore opportunities on the world market and bringing in investment and business activities from abroad. Korea needs to pursue a strategy of allowing capital and labor to go abroad to find the best investment and job opportunities while at the same time improving the attractiveness of the country as a place for an increasingly mobile workforce to live.

### **Future Scenarios**

Our simple model of the Korean economy emphasizes the importance of exports to China, the accumulations of assets generated by R&D, the narrowing of the technological differential between Korea and China, and changes in the size and nature of the Korean labor force.

In our analysis, we posit four strategic choices for Korean national planners. Although the strategies have names like “Base,” “Openness,” “R&D,” or “Education,” all should be considered mixed strategies made up of varying policy elements. Although these names evoke actions being discussed in Korean policy circles today, they are by no means to be considered definitive representations either of these policy alternatives or of the potential outcomes. The strategies are shown in Table S.1.

The analysis is conducted iteratively, seeking to assess the vulnerabilities of the candidate strategies to the uncertainties that have been identified, both parametric and structural. Our method allows us to view the performance of the strategies across large ensembles of alternative future scenarios. Using the metric of average annual rate of growth in GDP per capita for South Korea during the period leading to 2015, we assess each strategy across the ensemble of future scenarios.

**Table S.1**  
**Alternative Strategies for the Korean Economy**

Effect	Strategy			
	Base	Openness; Refocus Attention Away from China	Focus on R&D	Focus on Education
Knowledge base growth rate	10%	10%	<b>13%</b>	10%
Capital investment rate	27%	<b>29.7%</b>	27%	27%
Commit to exporting to China	1.0	<b>0.6</b>	<b>0.8</b>	<b>0.8</b>
Job creation rate	0.01%	0.01%	0.01%	<b>0.02%</b>
Speed of narrowing the technology gap between Korea and China	-0.05%	-0.05%	<b>-0.03%</b>	-0.05%
Adjusted labor effect	1.0	<b>1.02</b>	1.0	<b>1.03</b>

NOTE: Input values that differ from those of the base case are shown in boldface.

For example, under normal conditions, the “Base” strategy would be better than the other three. But if there is prolonged stagnation in Chinese growth, the Base strategy would be overtaken by the performance of both the Education and Openness strategies. This illustrates how changes in assumptions may lead to radical shifts in policy recommendations when focusing on optimality as a criterion. In this sense, the analysis begins where more traditional analyses would conclude.

The analysis then proceeds to examine how each strategy would perform relative to the strategy that would be optimal for the set of circumstances that defines the scenario. This measure of “regret” for pursuing a chosen strategic course shifts the focus from optimization for any particular assumed most likely set of circumstances to the property of robustness. We find that the R&D strategy, while it may not be optimal in all scenarios, appears to be the strongest of the four candidate strategies when measured according to the criterion of robustness.

Maintaining a technical advantage over China—or at least keeping the technological gap between Korea and China as wide as possible—could be an insurance policy against stressful times in the future and could maintain the relative attractiveness of Korean products if there is a downturn in China’s economic development. It would also give Korea a greater opportunity to explore and develop a presence in more-challenging markets.

Our four strategies are necessarily simple. Nevertheless, exploring the strategies highlights the value of their most important elements and serves as a means to make concrete some of the qualitative issues that are being discussed in Korea.