최종현학술원
Chey Institute for Advanced Studies

ITIF
INFORMATION TECHNOLOGY & INNOVATION FOUNDATION

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UNDERSTANDING AND COMPARING NATIONAL INNOVATION SYSTEMS: THE U.S., KOREA, CHINA, JAPAN, AND TAIWAN

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Chapter 1

Introduction

Robert D. ATKINSON

Nations are in a race for global innovation advantage. Recognizing that advanced, innovation-based industries provide a host of critical advantages, including higher national incomes, a better trade balance, and reduced dependency on potential adversary nations, most advanced and emerging economies have put in place policies to grow their innovation economy.

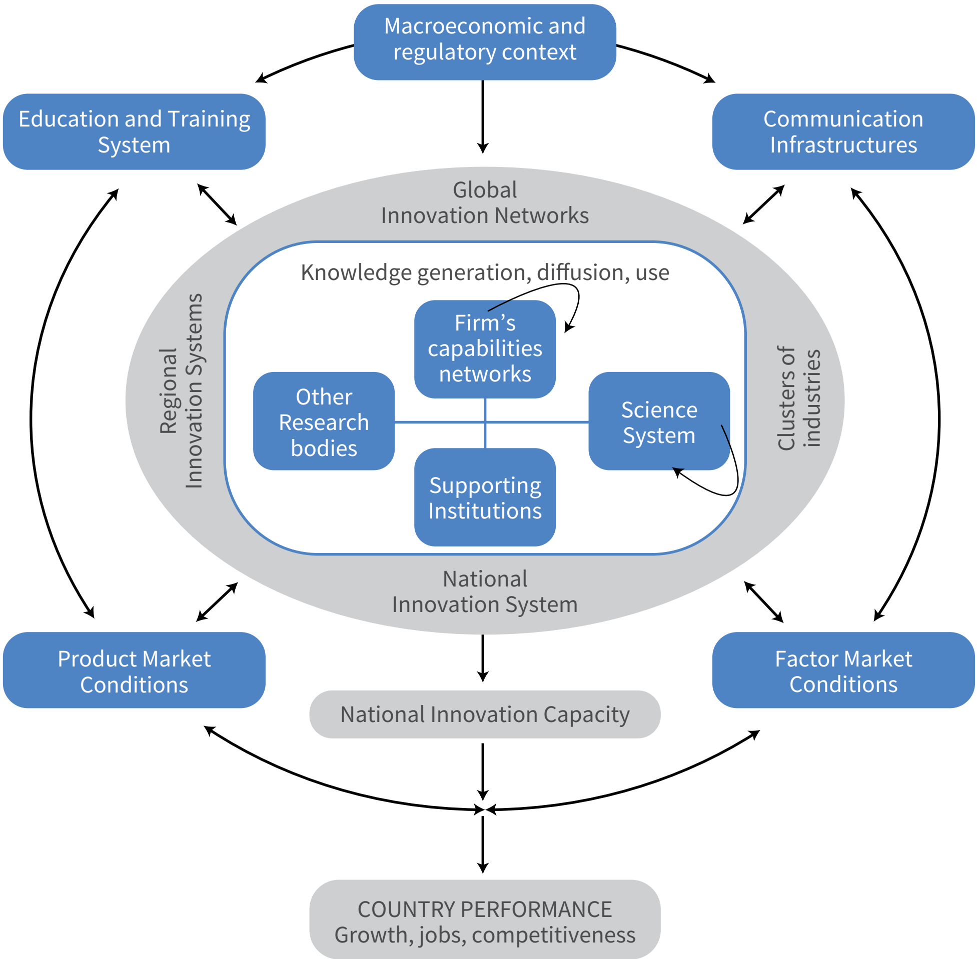
A conventional view may suggest that innovation is something that just takes place mainly in Silicon Valley garages and research and development (R&D) laboratories of private enterprises in a rather independent and idiosyncratic manner. However, innovation, in fact, is embedded in a national innovation system (NIS). Just as innovation is more than science and technology, an innovation system is more than those elements directly related to the promotion of science and technology. That is, innovations are *outcomes of a national system* including all economic, political, and other social institutions, for example, the financial system, organization of private firms, the pre-university educational system, industry-university collaboration system, labor markets, culture, regulatory, and tax policies, as is illustrated in Figure 1.1. Indeed, Christopher Freeman defines a national innovation system as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies." Likewise, Stan Metcalfe defines an NIS as:

> That set of distinct institutions jointly and individually contribute to the development and diffusion of new technologies and provides the framework within which governments form and implement policies to influence the innovation

process. As such it is a system of interconnected institutions to create, store, and transfer the knowledge, skills, and artifacts which define new technologies.[1]

A systematic understanding of innovation is an important approach because conventional economics, especially in Anglo-American economies, has proven limited in its ability to provide causal explanations for innovation outcomes. As Lundvall argued, the NIS way of thinking gained ground in part due to the fact that "mainstream macroeconomic theory and policy have failed to deliver an understanding and control of the factors behind international competitiveness and economic development."[2]

Figure 1.1. National Innovation Systems[3]



Some people may speculate that the concept of NIS, which was developed in the 1980s and 1990s, is less relevant these days, in an era of deeply integrated globalization. We disagree with this perspective. First, even with the globalization of finance and goods and services, national systems still matter in terms of how successful a nation's activities are. Second, in an era of rising competition for techno-economic dominance, e.g., between the U.S. and China, how the national or regional innovation systems are designed would bear critical significance for the scope of sustainable innovations.

The success of a nation's innovation depends on its national innovation system working effectively with synergy, not just on a few isolated ingredients (such as R&D spending) being put in place. Thus, a better understanding of the origins, paths of development, and operation of a nation's innovation system can help policymakers identify key strengths and weaknesses, and policy changes in order to enhance a nation's innovation performance. Because there are a variety of socioeconomic factors affecting innovations, national innovation systems differ across nations. Thus, we need to understand each system's unique strengths and weaknesses to gain insights for useful adaptation for each nation's innovation system.

This report compares and contrasts the national innovation systems (NIS) of five economies: the United States, Korea, China, Japan, and Taiwan to determine how well they are positioned to support innovation in key foundational and emerging technologies, such as semiconductors, smart manufacturing, biopharmaceuticals, advanced computing, robotics, and AI, although we will take a general view on technology rather than a sectoral view of those particular technologies. The purpose of the report is several-fold. First, by comparing and contrasting these five economies' national innovation systems, policymakers can better understand their own NIS weaknesses and challenges. Second, our comparative analysis enables policymakers to learn from other economies' NIS best practices. Finally, understanding the history and current state of NISs of the five economies will be helpful in designing potential frameworks and formats of innovation alliances among nations facing various global challenges, including the Chinese pursuit of technology dominance relying on illegitimate means, including breaching intellectual property rights.

We start our discussion by comparing the performance of innovations of the five economies using the same metrics in Chapter 2. To better understand the NIS in each economy, the Chey Institute and the Information Technology and Innovation Foundation (ITIF) convened a number of panels of innovation and innovation policy experts to discuss the strengths and weaknesses of the NISs of the five economies in the order of United States, Korea, China, Japan, and Taiwan, respectively in Chapters 3 to 7. The report is concluded in Chapter 8.

This monograph is particularly timely because global NIS systems are at an inflection point, in part because of the rise of China's advanced technology and innovation economy, and also because of the emergence of a new technology system grounded in advances in artificial intelligence and related technologies, coupled with an overarching focus on clean technology development.

In the case of the three other Asian economies, particularly Korea and Taiwan, there is a need to move their NIS from being focused on catchup and being a fast follower to being a global innovation leader. In addition, all three economies, especially Korea and Japan, need to spur entrepreneurial development, as both economies overly rely on large multinationals for innovation advantage. These economies also need to focus more on overall productivity growth, including in all sectors, not just export-driven ones. This is particularly important because all three face the demographic challenges of declining birth rates.

For China, the challenge looks different. China is following the path of prior "Asian Tigers" to develop its innovation and advanced industry economy, but if history is any guide, it will soon need to pivot away from its current top-down, directive approach. Korea and Japan utilized a more or less top-down approach through the 1980s, and Taiwan through the early 2000s, but all three economies have shifted to a less interventionist approach and a more supportive approach for the role of government: less focused on picking narrow winners, and more on enabling more robust innovations from the private sector. To be sure, China can continue to grow, especially its advanced export sectors, through its current "brute force" policies of subsidies, closed markets, and forced technology transfer. But at some point, in order to catch up to the global frontier of innovation, China will need to make a shift from a centralized command-and-control NIS to a decentralized supportive NIS, although it may well face political conflicts for sure. Whether it can do that under the control of the Chinese Communist Party remains to be seen, as such a step will require more domestic freedom.

The United States is in a different position. As the current leader of global innovation, its challenges when it comes to innovation systems are both easier and harder. They are easier in the sense that the leader can build upon existing strengths, especially in private enterprises and research universities. It is harder at the same time because forging new paths is often riskier and more expensive than following the trend, which is exactly because of the vintage capital from previous investments and also because of the forces of inertia. In addition, leaders can get lazy, both in terms of companies and the nation overall. As Clayton Christensen has written about the "innovator's dilemma":

> "Disruption" describes a process whereby a smaller company with fewer resources is able to successfully challenge established incumbent businesses. Specifically, as incumbents focus on improving their products and services for their most demanding (and usually most profitable) customers, they exceed the needs of some segments and ignore the needs of others.[4]. Entrants that prove disruptive begin by successfully targeting those overlooked segments, gaining a foothold by delivering more suitable functionality—frequently at a lower price. Incumbents, chasing higher profitability in more demanding segments, tend not to respond vigorously. Entrants then move up markets, delivering the performance that incumbents' mainstream customers require while preserving the advantages that drove their early success. When mainstream customers start adopting the entrants' offerings in volume, disruption occurs.[5]

We have seen this in the loss of global leadership in once dominant companies, including Lucent, General Electric, the "Big 3" automakers, Intel, and others. In part, this was due to an inability or unwillingness of the leaders to both invest in the next-generation technologies at the pace of their competitors and to attack challengers coming up from below.

This conservativism applies not just to the company level but also to the country level. As we find in this report, the level of national "hunger" for innovation leadership is much higher in China, Korea, and Taiwan than in the United States and Japan. In the United States, in particular, a post-capitalist ethos is gaining, rejecting growth, and seeing innovation as problematic, not as manna from heaven. Although, as Korea and Taiwan continue to boost their innovation capabilities, they face this risk as well.

The United States faces another challenge that the four Asian economies do not: a commitment to Anglo-American neo-classical economics. In this view of economics, innovation is exogenous ("manna from heaven") that the government can do little or nothing to promote, and so they do not. All industries are the same ("potato chips, computer chips: what's the difference?"), so there are no sectorally-based policies to support particular industries. With the passage of the Chips and Science Act and the Inflation Reduction Act, both are beginning to change in the United States, but much less than many believe. Market fundamentalism still plays a very strong role in shaping the U.S. NIS. Indeed, there is little understanding that the United States even has an NIS that needs to be reshaped by government policy. Unlike the other four nations, there is very little government-driven analysis for innovation and industry promotion to assess the associated risks and opportunities.

The national innovation systems under the new global order are to be different from the past. The features of competition among global powers have changed. The competition between the U.S. and the Soviet Union was about security challenges based on ideology. The competition between the U.S. and Japan in the 1980s was about economic challenges, but they shared a similar value system. Upon the rise of China as a global economic power since the late 1990s, China has continued to pursue global hegemony by expanding its technology frontier in order to eventually expand its political as well as military frontiers. This created a new phenomenon of competition based on the so-called "economic security" among global powers and their alliance. The fundamental channel of global competition is now technology, neither the economy nor the politics alone. Thus, the coordination of national innovation systems, which are behind the realized technology development, has now become the key dimension of international cooperation, and forming the right coalition among the concerned nations is critical. We should understand and design a national innovation system from this perspective to adapt to this new global order.

Finally, the potential of a host of important technological innovations, including those based on genomics and related biotechnologies, AI, autonomous systems, and new materials, opens important opportunities for progress, including faster global productivity growth. It is critical to coordinate national innovation systems among nations sharing similar value systems and security stakeholders to take advantage of these opportunities and to expand the scope of potential innovations.

1. John Metcalfe, "The economic foundations of technology policy: Equilibrium and evolutionary perspectives," in *Handbook of the Economics of Innovation and Technological Change*, edited by Paul Stoneman (Oxford: Blackwell, 1995)
2. Pedro Conceicao et al., *Innovation, Competence Building and Social Cohesion in Europe: Towards a Learning Society,* (Edward Elgar Publishing, Cheltenham, UK, 2000) p. 214.
3. OECD, *Managing National Innovation Systems*, (OECD Publishing, Paris, 1999) https://doi.org/10.1787/9789264189416-en.
4. Hirotaka Takeuchi and John Quelch, "Quality is More Than Making a Good Product," *Harvard Business Review,* July 1983, https://hbr.org/1983/07/quality-is-more-than-making-a-good-product.
5. Clayton Christensen, Michael Raynor, and Rory McDonald, "What is Disruptive Innovation?" *Harvard Business Review,* December 2015, https://hbr.org/2015/12/what-is-disruptive-innovation.

Chapter 2

Quantitative Comparison of Five National Innovation Systems

JEONG Hyeok, Robert D. ATKINSON

Science and technology concern themselves with unlocking the mysteries of nature. Meanwhile, there is less of a mystery surrounding the core building block inputs upon which nations' S&T enterprises rely—namely financial investment in basic and applied scientific research and technology development, a strong base of highly-educated human capital, financing to develop knowledge and turn it into globally competitive businesses. Each nation, and the scientists, entrepreneurs, and enterprises therein turn these foundational S&T inputs into outputs such as scientific and technical publications and patents, and eventually to final innovation outcomes such as new technologies and their applications to private sector enterprises and national defense systems.

Before assessing each economy's national innovation system, it's worth comparing the five economies from the measures of national innovation input, outputs, and outcomes. There exist some reports that attempt to measure innovation capabilities but they often suffer from weak relevance by including too remote measures in their indices. For example, the World Economic Forum index includes indicators such as organized crime, homicide rates, budget transparency, energy efficiency regulation, quality of land administration, environment-related treaties, trade tariffs (low is good), labor tax rate, and many more.[1] Most of these have no real relationship to innovation. World Intellectual Property Organization(WIPO)'s Global Innovation Index(GII) data are more relevant but still include measures such as electricity consumption, loans from microfinance organizations, and the size of the domestic market. Furthermore, most studies rely at least in part on opinion surveys, which are subject to bias.

In this chapter, we first compare 21 performance indicators that we believe are more directly related to innovation capabilities and performance across the five economies in our study. Some indicators for Taiwan are not available because of the UN's limitation of enlisting countries for some databases. All measures are adjusted to reflect the size of the economy. For all indicators, we sought the most recent period available and tried to compare it to a base year approximately a decade prior. Then, we discuss the socio-economic system aspects of innovations of the five economies, which make critical influences on the above innovation measures, focusing on three dimensions: concentration of employment and innovation, innovation culture, and the role of government.

1. Performance Metrics of Innovation

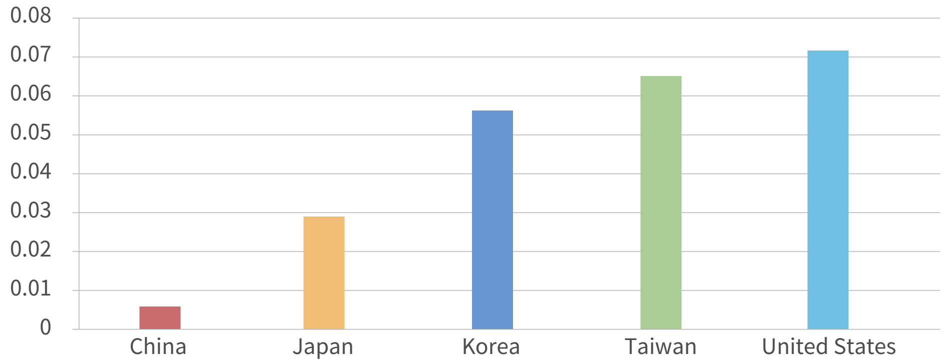
1.1. Science and Technology Inputs

Science and technology inputs are the foundational "ingredients" that are used to create ideas for innovations. This section compares five economies from these measures.

Quality of Universities

Universities play a key role in national innovation systems, not only because they teach STEM students, but also because they conduct research that can be used by innovators. We use data from the 2023 QS World University Rankings, adding the scores of all the universities in each nation and dividing it by population. The results are in Figure 2.1. As expected, given the long tradition of university funding in the United States, the United States ranks first. However, Taiwan ranks second, with leading universities such as National Taiwan University, National Tsing Hua University, and National Yang Ming Chiao Tung University scoring high. Korea ranks third. Strikingly, given Japan's long status as a developed economy, its university quality per capita is quite low. Finally, even though China has some world-leading universities, like Peking University and Tsinghua University, China has too few high-quality universities relative to its population.

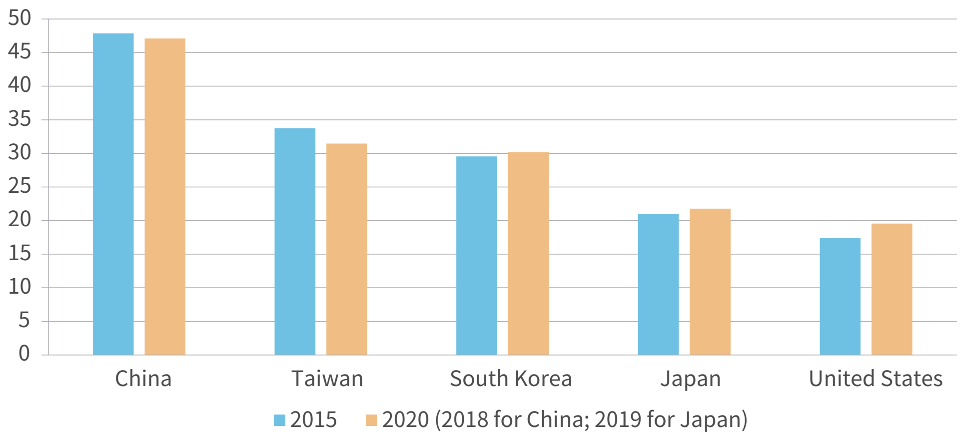
Figure 2.1. **Number of Universities Measured by Quality as a Share of Population**



S&T Researchers

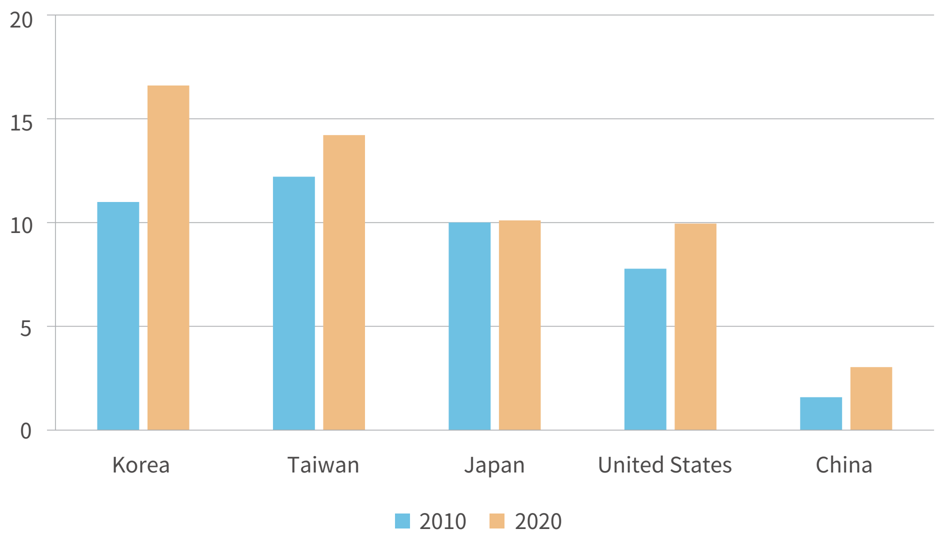
An input indicator for national S&T talent is the share of college graduates majoring in STEM fields. As Figure 2.2 shows, China leads in this innovation measure, while the United States and Japan lag behind. In part, this reflects the common trend of structural transformation from manufacturing jobs to professional service sector jobs such as lawyers and doctors, as the income level passes a high enough threshold as in the U.S., Japan, and Korea. On the other hand, China's remarkably high share of STEM college graduates also reflects China's strong demand and government support for this skill set as a global manufacturer. However, whether the STEM graduates contribute to idea production or innovation outcomes is a different story.

Figure 2.2. **STEM Graduates as % of Total Graduates**[2]



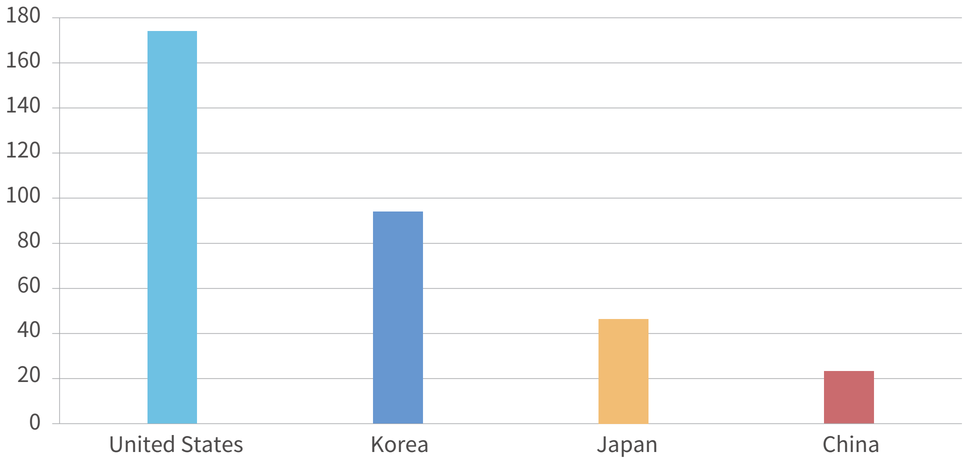
A more direct foundational ingredient in technological innovation is the number of science and engineering researchers per worker. As shown in Figure 2.3 (total number of researchers per thousand employed in 2010 and 2020), Korea is the leading country in 2020, followed by Taiwan, Japan and the United States at par, and China at a distant fifth. It is striking that Chinese research worker share is so low, given their high share of S&T graduates as a share of total graduates and their higher level of business R&D. The first factor could be explained that most of these graduates are still in their 20s and 30s and that fewer of older workers have these credentials. It is also likely that official Chinese statistics on business R&D are overstated because of the pressures from the Chinese government on business companies to look like they are doing more R&D. In terms of growth trend, Japan's lack of improvement is striking. The most significant improvement happened in Korea and China. Chinese fast growth is due to the low base effect. Thus, in terms of both size and growth in the number of researchers, Korea is a leading country.

Figure 2.3. Total Researchers Per Thousand of Total Employment[3]



The social value of researchers may change over time depending on which technologies are the main driving force for a given period. For the recent era of AI, a critical indicator of innovation input is the intensity of artificial intelligence researchers. Figure 2.4 compares the number of AI researchers per million workers, where the AI researcher is defined as a researcher within the field of AI who has published patents or papers for distribution regarding AI in the last 10 years. The United States leads by a significant margin, with Korea ranking second. Japan, which has generally lagged in software, ranks third. Even though China has invested considerably in AI training and research, actual AI researcher share is still low, which is about one-ninth of the US level.

Figure 2.4. **Number of AI Researchers per Million Workers (2018)**[4]



Business Research and Development (R&D) Investment

Countries' R&D investments represent perhaps the single most important input to innovation, in particular the R&D investment by business sector. As Figure 2.5 shows, Korea leads in this measure, followed by Taiwan, the United States, Japan, and China. The low performance of China reflects that despite all its efforts to grow its innovation economy, China is still a developing economy that is based more on production and copying than innovation and invention. It is striking that while all 5 economies saw significant increases in business R&D between 2011 and 2021, Japan virtually stagnated.

Regarding the total R&D investment relative to GDP by including the public-sector R&D investment, the above features remain virtually the same, as shown in Figure 2.6. In fact, the cross-country patterns of the gaps in level and growth for this measure are reinforced by including public-sector R&D investment. This can be a surprise for someone who might have thought that Chinese R&D was driven mainly by government support.

Figure 2.5. Business R&D as % of GDP[5]

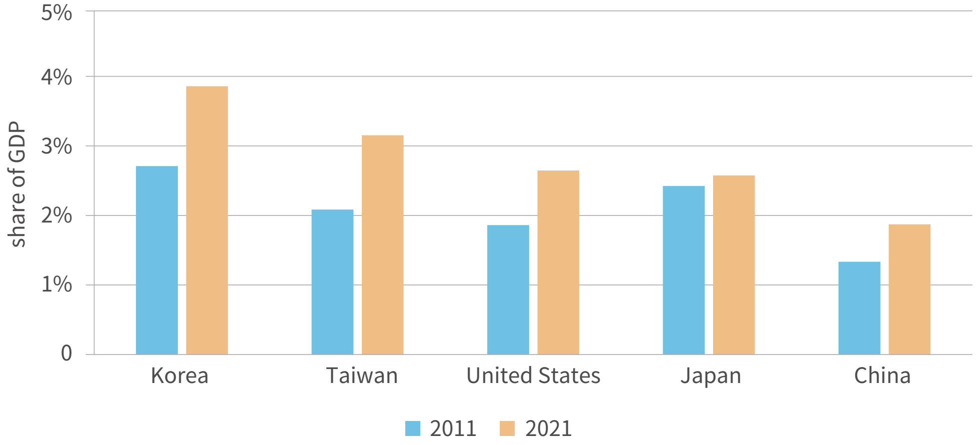
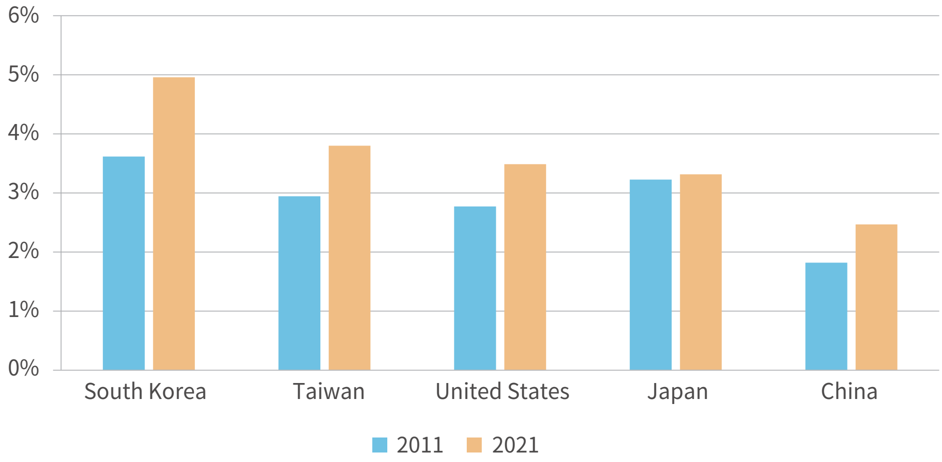
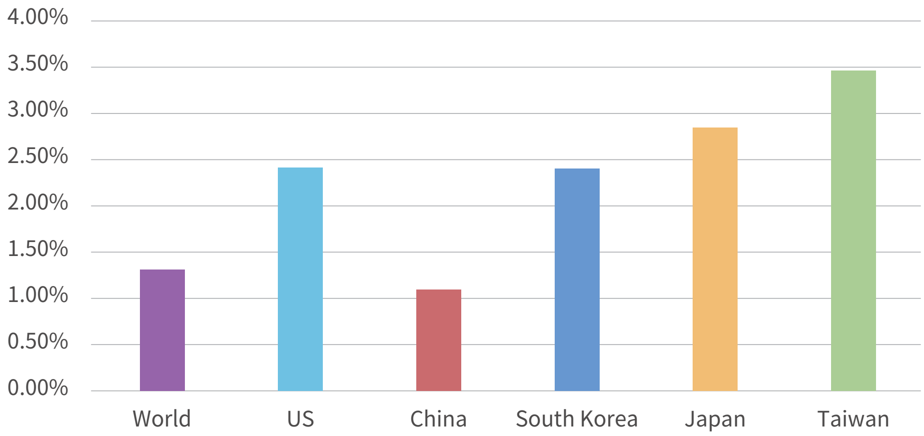


Figure 2.6. Total R&D as % of GDP[6]



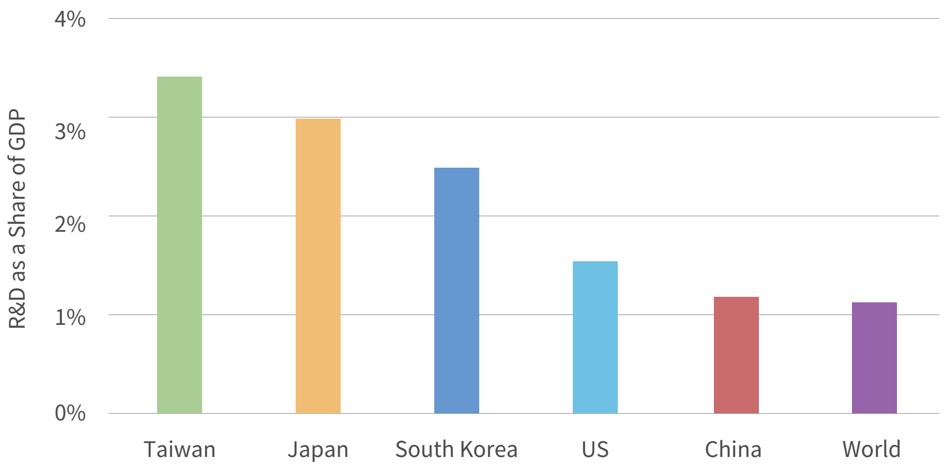
Another measure of business R&D is the R&D intensity. *The 2022 EU Industrial R&D Investment Scoreboard* reports the R&D spending intensity of the world's top 2,500 R&D companies.[7] While the United States has the largest share of the world's top 2,500 most R&D-intense companies, regarding the average intensity of R&D, Taiwan is the highest, followed by Japan and Korea. American companies' R&D intensity at 2.4% is similar to the Korean level, as is shown in Figure 2.7. The Chinese R&D intensity among the top R&D firms is 1.1%, which is lower than half of the American or Korean level, and one-third of Taiwanese.

Figure 2.7. Average R&D Intensity of Enterprises in *2022 EU Industrial R&D Investment Scoreboard*[8]



It is worth noticing that the United States' high level of R&D intensity is because of the very large R&D spending levels of a few big tech companies in the software and computer services sector, such as Microsoft, Facebook, and Alphabet. As shown in Figure 2.8, excluding these software and computer services industries, the U.S. level of R&D intensity drops significantly, falling far behind those of Taiwan, Japan, and Korea, though it is still higher than that of China. This reflects the weak R&D spending of the U.S. companies in advanced manufacturing sectors.

Figure 2.8. R&D Spending per GDP of Firms Except Software and Computer Services Sector[9]

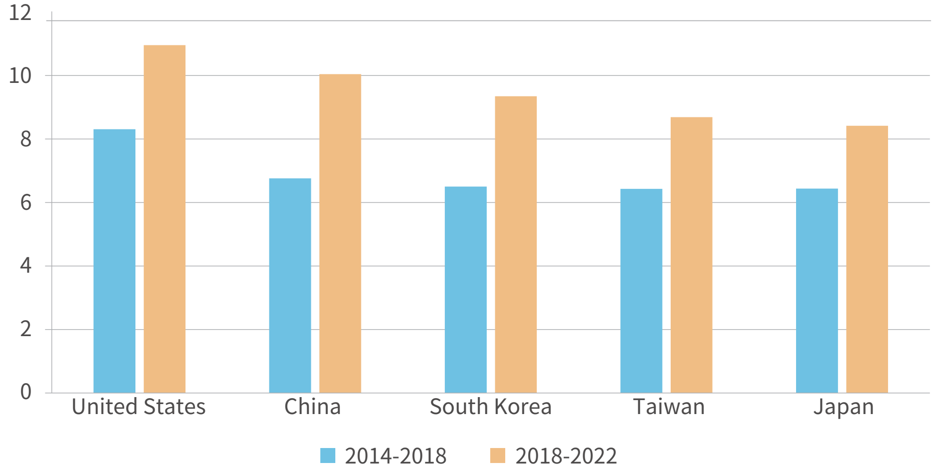


1.2. Science and Technology Outputs and Finance

S&T Scholarly Idea Production

Scholarly knowledge is an important input to innovation. One metric of this innovation input is the number of scholarly journal publications. However, all journal publications are not equal. One measure of quality is the number of citations each paper receives. Figure 2.9 shows that the United States leads, on the basis of the historically high quality of America's research universities, but China ranks second, a testament to the major effort the Chinese government has made to support academic research. However, the differences among all five economies are not large (9 to 11). Furthermore, all five economies have shown increases since 2014.

Figure 2.9. Citations Per Paper[10]



Patents

The number of patents is an indicator measuring the size of the pool of innovative ideas but not the final outcomes. Patents only matter for innovation if the discovery is commercialized. Because of significant "over-patenting" in the Chinese patent system, we only use indicators from either the United States or patents filed in multiple jurisdictions. One measure is patent applications made to five major countries. For this measure, Japan, Korea, and Taiwan are significantly in the lead to the U.S. and China, with over 400 applications for a million inhabitants, as shown in Figure 2.10. Surprisingly, the United States' level is lower than that of the top three innovative Asian countries, although it is significantly above China's level.

Another measure is the number of patents 'granted' (normalized by population), which measures the flow of *useful* ideas. Among the patents filed in the U.S. Patent and Trademark Office, Taiwan leads in this measure, followed by the United States, Korea, and Japan with small margins. However, there exists a significant gap between China and the rest four economies.

Figure 2.10. IP5 Patent Applications per Million Persons[11]

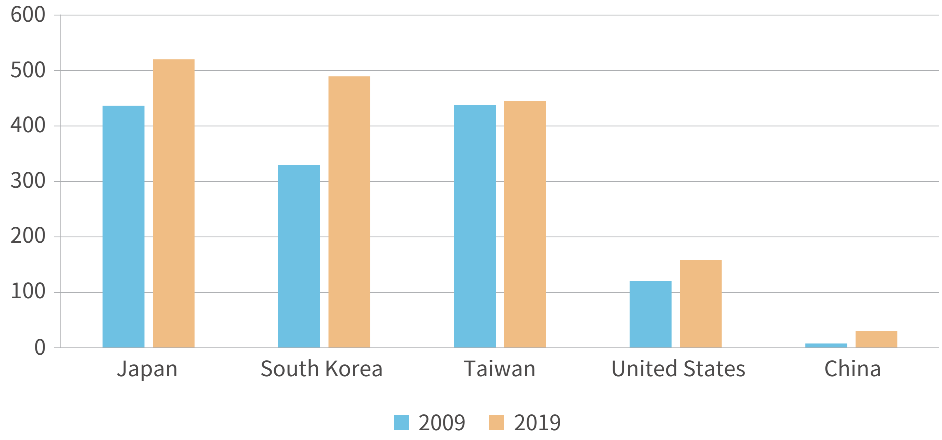
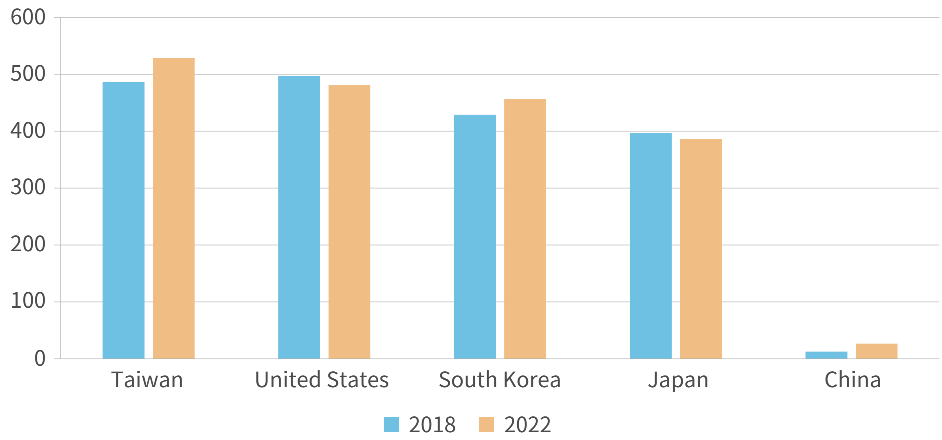
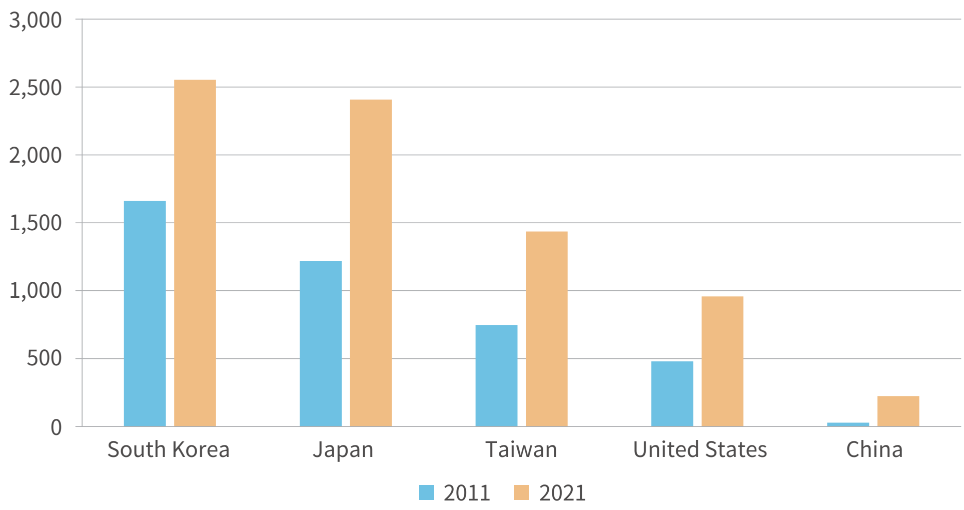


Figure 2.11. USPTO Granted Patents per Million Persons[12]



Another measure for useful idea production is the total *patents in force*, which are defined as patents that can exclude others from using or distributing an invention for a given period of time. As shown in Figure 2.12, Korea leads, followed by Japan. Again, it is striking that the United States is low in this innovation measure, ranked as the fourth with significant gaps compared to Korea and Japan. China is still a laggard, reflecting that despite all the push for innovation by the Chinese government, China still relies extensively on copying ideas (much of it in illegal manners) rather than producing ideas. However, its growth rate during the 2011-2021 period was very high.

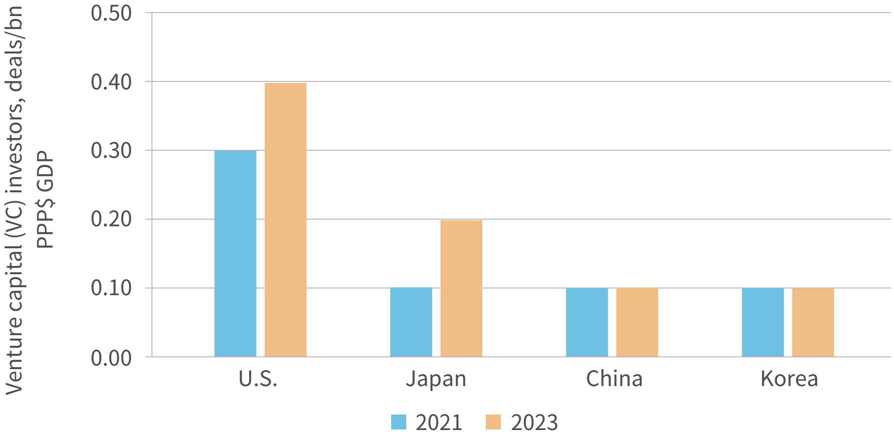
Figure 2.12. Patents in Force per Capita[13]



Venture Capital and Other Business Financing

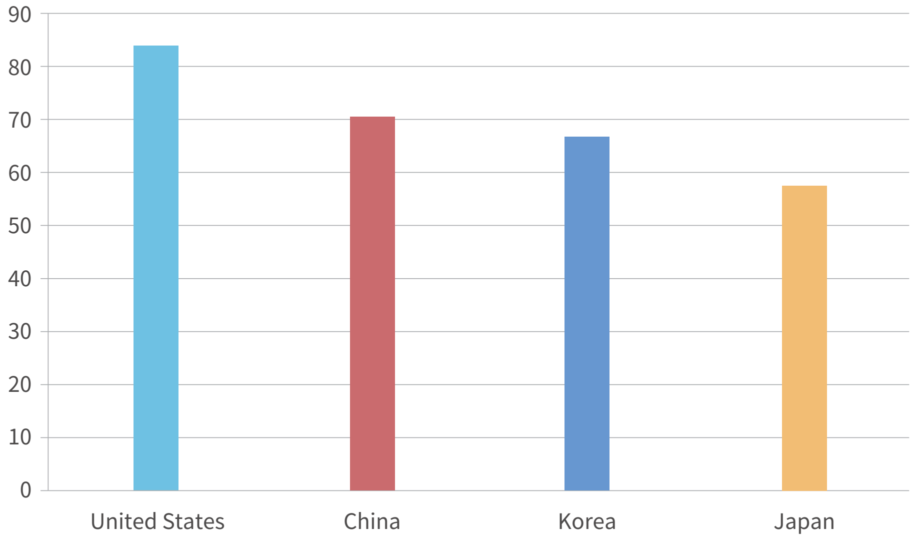
Venture capital is an ingredient (capital to innovative startups) but also an output reflecting how many innovative startups are activated in an economy. Figure 2.13 compares the venture capital deals normalized by the PPP-adjusted GDP across our sample countries except Taiwan. Not surprisingly, the United States leads in this measure with discrete gaps from other countries, twice as much as Japan and four times as much as Korea and China.[14] Furthermore, this measure grew between 2021 and 2023 in the United States and Japan, but stagnant in Korea and China.

Figure 2.13. **Venture Capital (VC) Investors, Deals/Billion PPP$ GDP**[15]



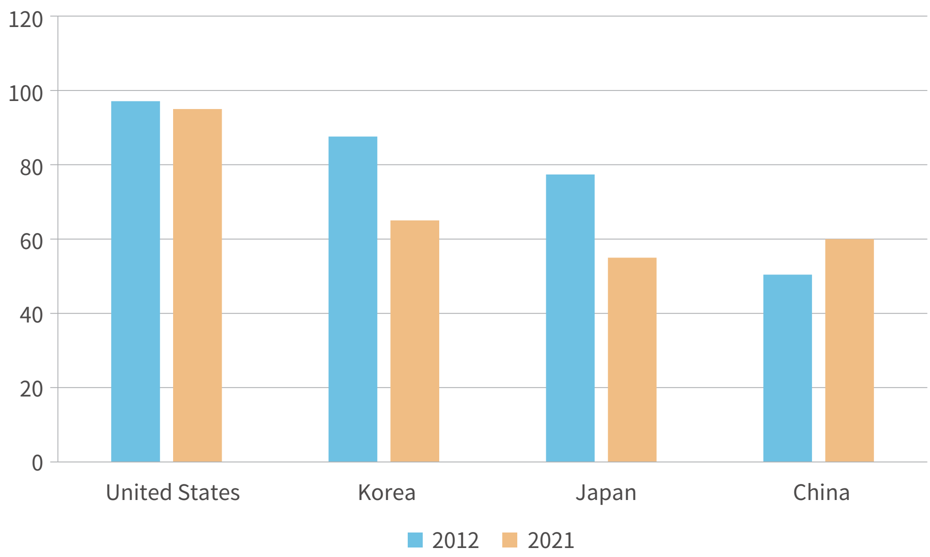
Financing for startups, particularly fast-growing ones, is a key enabler of innovation because startups often bring new ideas and innovations to the markets. One indicator of this aspect is a survey of experts on the question. Figure 2.14 reflects finance experts' assessment and perception of a country's conditions for starting and growing firms. According to this survey, the United States leads, followed by China, Korea and lastly Japan.

Figure 2.14. **Financing of startups and scale-ups, 2023 (Survey question)**[16]



The World Bank's Ease of Doing Business survey assesses the ease of getting credit for businesses. Access to credit is a necessary condition for establishing and running private sector businesses, where the most innovations are realized. Figure 2.15 shows that the U.S. significantly leads in this measure. As the economy matures, access to credit becomes easier. However, it deteriorated in Korea and Japan, while it improved in China.

Figure 2.15. Ease of Getting Credit[17]



Software Spending and ICT Use

Innovation is not just about new products It is also about how goods and services are produced (e.g. process innovation). Software spending is a key indicator of IT-based process innovation, which in turn is critical to productivity growth. This is an area where the United States maintains the leading position at 1 percent of GDP, considerably higher than China, Japan, and Korea (see Figure 2.16). Strikingly, Korea's software spending as a share of GDP actually fell between 2013 and 2023.

Figure 2.16. **Software spending as a percent of GDP**[18]

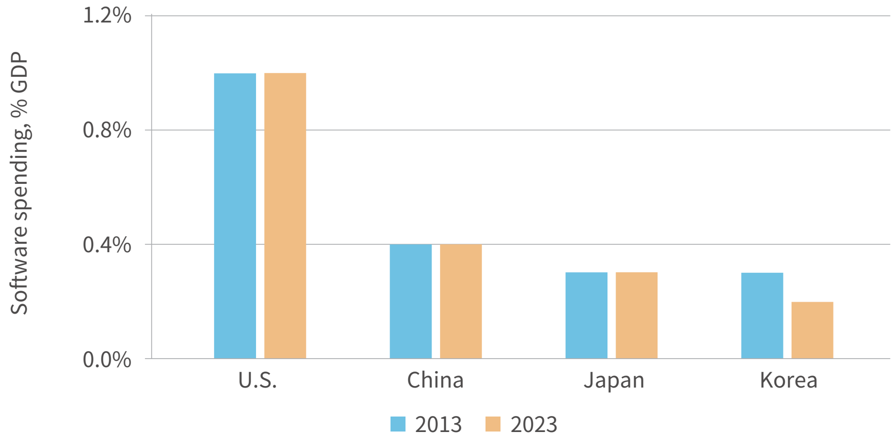
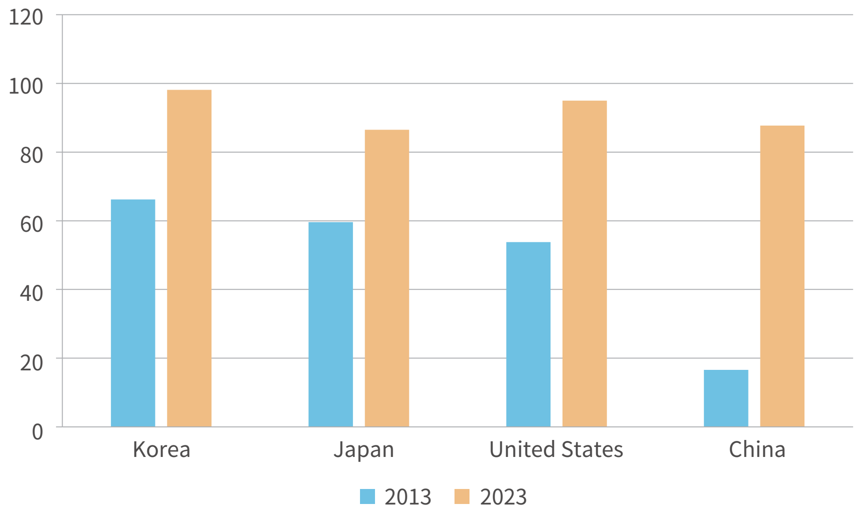


Figure 2.17 shows the ICT use index which is a composite index based on internet usage, fixed and mobile broadband internet subscriptions, and internet traffic to measure ICT usage within a country. Korea has led in both 2013 and 2023. Japan was second in 2013 but fell to last by 2023. The United States ranks second, and China third. China made a remarkable leap during the last decade in this measure.

Figure 2.17. **ICT Use Index**[19]



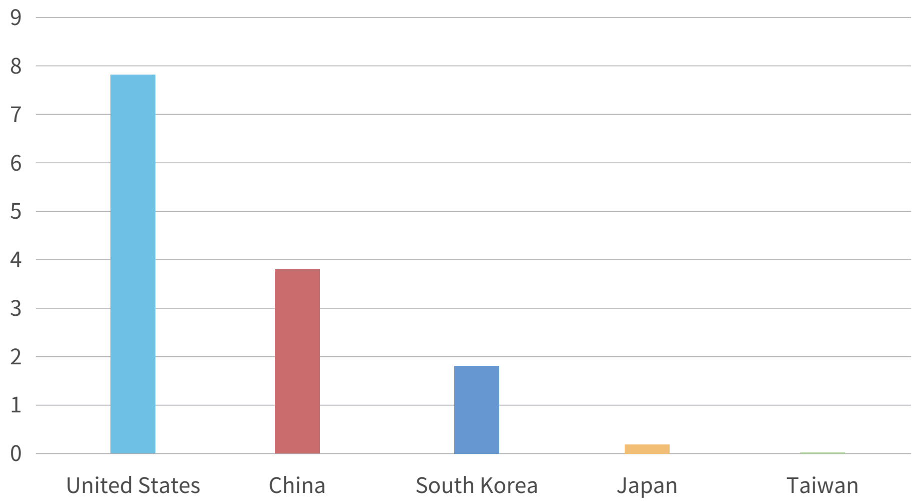
1.3. Innovation Outcomes

Finally, we discuss some critical indicators measuring the actual innovation outcomes (including firm formation and production) that come from a national innovation system.

Unicorns

The Global Innovation Index defines unicorn companies as startups worth over one billion USD.[20] They reflect the creation of very fast-growing firms, many of which are S&T-based. Not surprisingly, given the robust entrepreneurialism of the U.S., the United States leads in unicorn valuation to GDP, with a rate approximately twice as high as China, and four times of Korea, as shown in Figure 2.18. Unicorns are virtually negligible in both Japan and Taiwan.

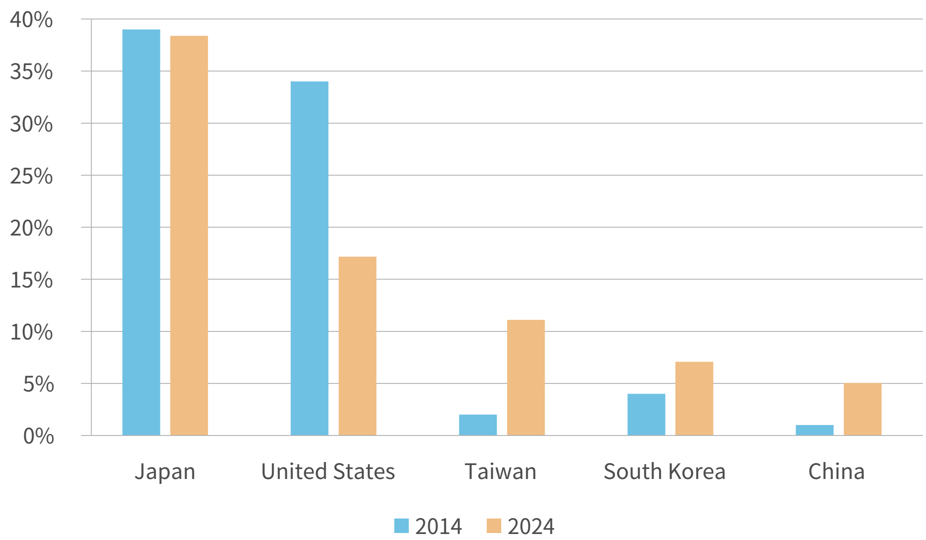
Figure 2.18. **Unicorn Valuation to GDP**[21]



Innovative Companies

One of the critical goals of the national innovation system is to promote innovative companies. Clarivate's Top 100 Global Innovators list provides this information. Japan leads in this measure as of now and also a decade ago (38 ~ 39%), followed by the U.S. Although the U.S. still ranks second, its share in the top 100 global innovative companies sharply declined from 34% in 2014 to 17% in 2024. In contrast, this indicator significantly increased in Taiwan (2% to 11%), Korea (4% to 7%), and China (1% to 5%). In 2024, Clarivate provides not just the list of 100 companies but also their rankings. Narrowing down the top hundred list to the top ten list, there are 6 companies in Japan, 2 in Korea, one in the U.S., and one in China.

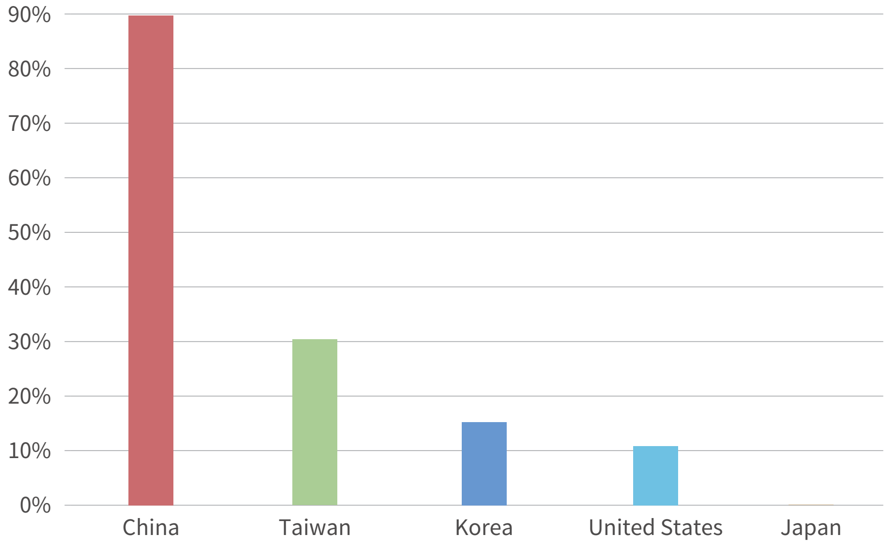
Figure 2.19. Share of Top 100 Most Innovative Companies[22]



Labor Productivity Growth

Labor productivity growth is one of the most fundamental drivers of improvement of the living standards of a nation. Figure 2.20 shows the decade (2012-2022) growth rate of labor productivity, which is calculated as real GDP in 2017 PPP $ per worker. China ranks first in almost doubling speed during this period. This in part reflects the catch-up growth effect, which is not related to genuine productivity growth. The catchup-driven labor productivity growth will eventually converge to zero. Among the countries with higher levels of GDP per worker, Taiwan leads in this growth measure, followed by Korea. Surprisingly, Japan has been stagnant with no productivity growth over this period, which started in the 1990s.

Figure 2.20. **Labor Productivity Growth Rate 2012–2022**[23]



Comparative Advantages of Advanced Industrial Sectors

The output of technology-based industrial sectors is the basis of the national innovation system as well as its consequences. ITIF's Hamilton Index provides information about this, measuring the aggregate value of output from 10 advanced industrial sectors (IT and information services; computers, electronics, and optical products; chemicals; pharmaceuticals and biotechnology; machinery and equipment; fabricated metals; motor vehicles; other transportation equipment; basic metals; electrical equipment) for each national economy, and then measuring an industry's share of an economy relative to the global industry's share of the global economy, being defined as "location quotient."[24] The location quotient is simply a comparative advantage measure for domestic production for a given industry, indicating the relative strength of production of the particular industry relative to the global economy.

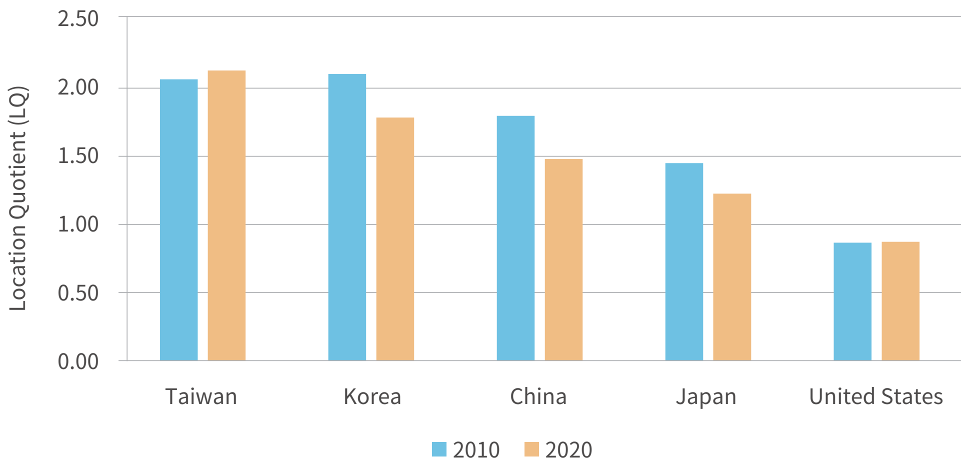
Figure 2.21 compares the average location quotient for the chosen 10 industries. The relevance of this indicator as an innovation measure depends on whether the selected industries are in line with actual innovations. Presuming such relevance, Taiwan leads in this measure as of the year 2020. In 2010, Korea was a leading country, but due to the drop in Korean LQ (while it slightly rose in Taiwan), Taiwan took the leading position.

Korea still occupies the second position. The reason behind such strength of the advanced industrial production of Taiwan and Korea is the common, strong performances in computers and semiconductors.

Interestingly, it is not just Korea where the overall LQ fell during the 2010-2020 period. It fell both in China and Japan. It is rather surprising to observe such a decline particularly in China, where overwhelming efforts were made to build its strength in advanced industries through "Made in China: 2025." However, it is important to notice that LQ is a relative concept so that this fall may reflect the faster growth of output in non-Hamiltonian sectors, rather than the absolute decline in the Hamiltonian sectors. The lost grip of Japan in these advanced industrial sectors which happened before 2010 continued to be reinforced until 2020.

The most striking observation is the weak comparative advantage of the U.S. in the advanced industrial sectors throughout the 2010-2020 period. The LQs are not only lower than those of Taiwan, Korea, China, and Japan but also lower than unity, meaning the U.S. economy's production share of the advanced industrial sectors is lower than the global average. This reflects the offshoring of these industries and also the loss of competitiveness in a range of U.S. advanced industrial sectors (other than aerospace and software and information services).

Figure 2.21. Location Quotient for Hamilton Index Industries[25]



2. Aspects of the Socio-economic System of Innovation

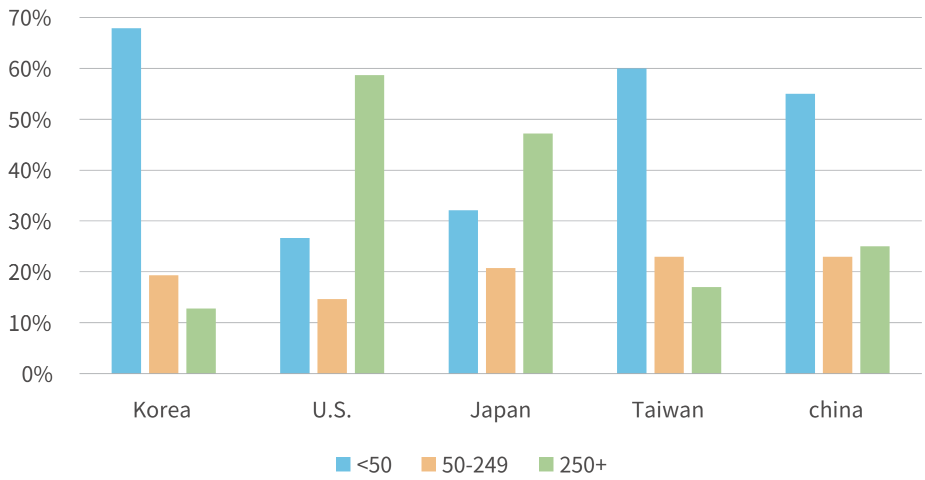
In the previous section, we compare the performance measures in relation to innovation across the five economies. Those performance measures are influenced by the underlying socio-economic system of each nation. We explore such socio-economic system aspects of the NIS of the five economies, focusing on three dimensions: concentration of employment and innovation, innovation culture, and the role of government.

2.1. Concentration of Employment and Innovation

The formation of entrepreneurship is the starting point of innovation. Thus, the promotion of the competitive entry of new firms, although they are small, is important for fostering the pool of potential innovations. At the same time, it is usually large firms that actually materialize innovative ideas into marketable products. In all economies, small firms outnumber large ones. However, what matters is the distribution of employment, the value-added, and investment for R&D across firm size, in measuring their economic significance and contributions to NIS. These aspects differ a lot across nations. For example, Germany has a relatively even distribution of employment and value-added, due to the thick mass of manufacturing employment by middle-sized firms ("Mittelstand") rather than by big firms. Among the five economies in our study, the majority of job creation is made by small companies (size of fewer than 50 employees) in Korea, Taiwan, and China, as shown in Figure 2.22. In these three economies, the contribution share of large companies (size of employees is 250 or more) to job creation is fairly small, 11% (Korea) to 22% (China). In contrast, Japanese large firms contribute 47 percent of employment. The United States has an even higher share (57 percent) for this measure.

Using the data from the EU Global 2500 R&D Spenders Report in 2022, we can quantify the degree of concentration of innovation efforts by calculating the contribution shares of R&D investment by the top 10% innovators to total R&D spending of each economy. The total number of firms differs across economies, and we identify the top innovators by top 10% rather than by fixed number of firms. Figure 2.23 displays the top 10% of firms' R&D spending shares of the five economies. The R&D concentration is highest in Korea (76%), closely followed by the U.S. (74%), and then by China (61%), Taiwan (61%), and Japan (57%). Figure 2.24 shows the top 10% of firms' average R&D spending amount. The top 10% of Korean firms invest the largest amount (6,422 Million USD per company) in R&D, again closely followed by the U.S. (5,812 Million USD per company). There exists a discrete gap between these two leading countries and the rest three economies (3,292 Million USD for Taiwan, 2,272 Million USD for Japan, and 2,271 Million USD for China).

Figure 2.22. Employment Share by Firm Size[26]



Combining the observations of the different distributions of employment and R&D spending across the five economies, we can infer that R&D spending and job creation do not go hand in hand in Korea, Taiwan, and China. R&D spending is concentrated among a few leading companies but their contribution to employment is much smaller in these three economies. This pattern is particularly noticeable in Korea. In the case of the U.S., R&D spending is similarly concentrated among a few leading companies, but their job creation share is also big. That is, in the U.S., large innovation-leading companies lead the job creation as well. Japan shows an intermediate pattern. The "mismatch" between innovation input (R&D spending) and job creation in Korea, Taiwan, and China can be a limiting factor for the sustainability of NIS because there exist potential conflicts between innovative technologies and employment during the initial phase of developing innovative ideas and products. Furthermore, the numbers of the top 10% R&D spending companies are only 5 for Korea and 8 for Taiwan (they are 23 for Japan, 68 for China, and 83 for the U.S.). If the innovation inputs as well as their fruits are concentrated among such a few companies without creating proportionate jobs, the NIS with such a socio-economic structure is likely to be vulnerable to both political and external shocks.

Figure 2.23. **Top 10% Firms' R&D Spending Share**

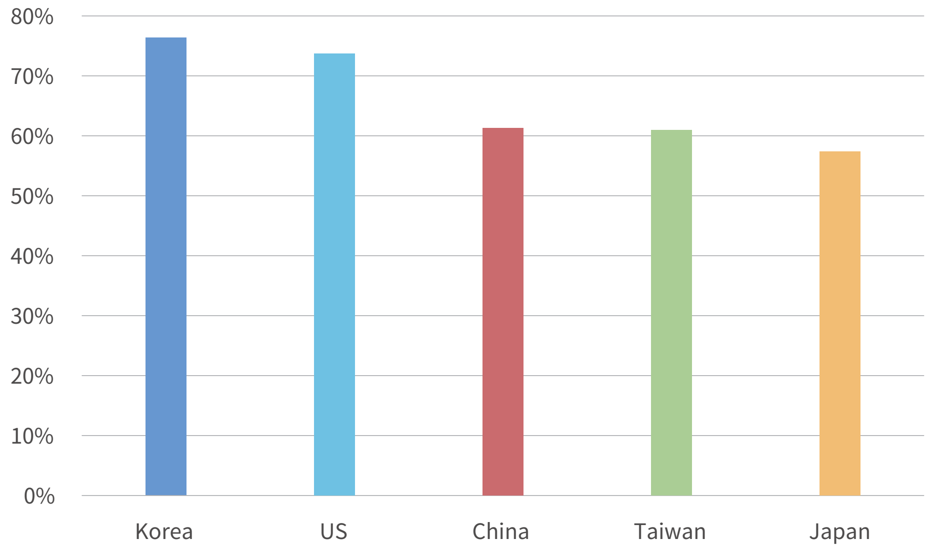
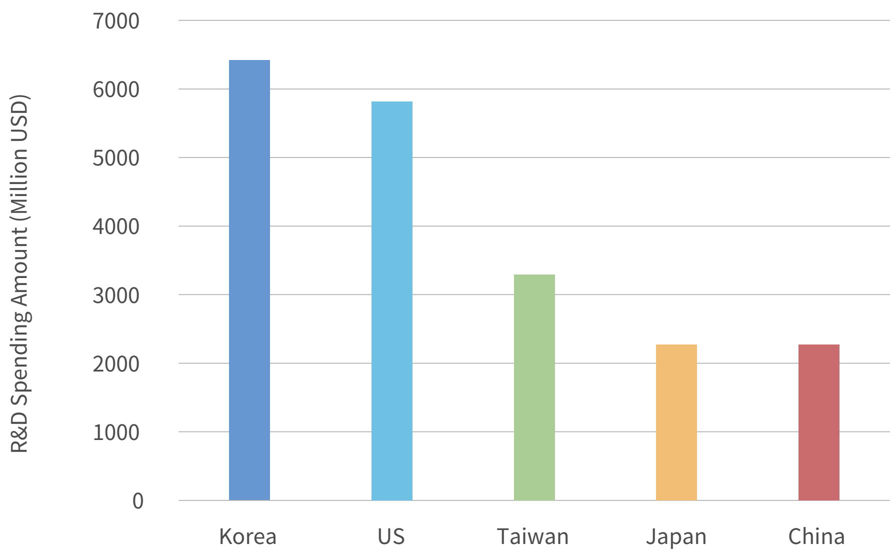


Figure 2.24. **Top 10% Firms' R&D Spending Amount**

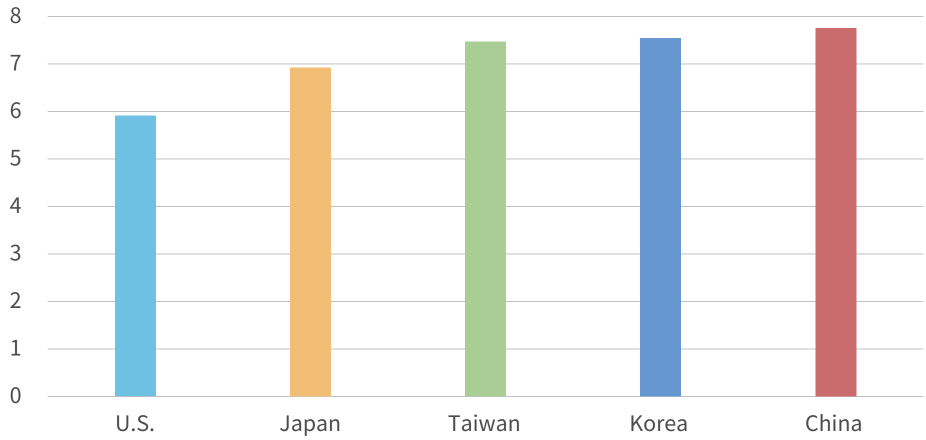


2.2. Innovation Culture

The cultural atmosphere which is supportive of new ideas and the consequential changes is critical for innovation. Despite the difficulty of measuring the culture of innovation, a measure of public attitudes toward technological change provides us with a potential metric for the innovation culture of a nation. The World Values Survey asks around 50 nations the following question: "Do you agree or disagree with the notion that science and technology make our way of life change too fast?" We interpret that the lower the score to this negative question, respondents of the nation are favorable to innovations.

The United States scores the lowest, i.e., the culture of embracing innovation seems to be the strongest in the U.S. among the five economies. See Figure 2.25. A noticeable gap exists between the U.S. and the rest four Asian economies. The ordering among the four Asian economies (Japan, Taiwan, Korea, and China in increasing order) appears to be related to the length of history of industrialization. China is the least favorable to innovation among the five economies. At first look, this may be surprising because of the aggressive efforts for technological catchup by China. However, the prevalence of fear of technological changes seems natural in an economy like China where the changes are driven too fast and there exists a gap in perception changes between the government and ordinary people about what are the desirable technological changes.

Figure 2.25. Negative Public Attitude Score Toward Technological Changes



As Mark Zachary Taylor suggests in *The Politics of Innovation: Why Some Countries Are Better Than Others at Science and Technology,* a key factor in a nation's success in science and technology is "creative insecurity." The nations experiencing more "existential risks" are more likely to create the institutional and policy responses to succeed in science and technology for their survival. This applies to both Korea and Taiwan, with the former facing threats from North Korea and China, and the latter from China.

Japan also felt this kind of threat when Commodore Perry's black ships were harboring Tokyo Bay in 1853, which was one of the driving forces of many institutional reforms and technological innovations afterward. However, the sense of such existential urgency has declined to virtually nil in Japan. The United States had a similar urgency during the Cold War period with the Soviet Union. Indeed, this was a key reason that the U.S. government spent more on R&D in the early 1960s than every other government and non-U.S. business in the world combined. Since the collapse of the Soviet Union, the United States has been seduced by the "end of history" myth and the sense of the national urgency has greatly diminished. This is one reason why the U.S. R&D spending share of GDP has fallen to a level that was not seen after the pre-era of the Soviet Union's launch of Sputnik.

China has a different motive for pushing national innovations. China's long desire for the revival of its global dominance for wealth and power, as Orville Schell argued, became visible after its take-off by the economic reform and openness, and has thrust itself to take the global leadership in science and technology to achieve the Chinese Dream.

In sum, the driving forces to push national innovations in relation to national urgency are strong in Korea, Taiwan, and China, compared to Japan and the United States, although the public attitudes toward embracing innovations are opposite.

2.3. Role of Government

There are different perspectives on the role of government in promoting innovation across the five economies. Many innovation experts in the United States argue that innovation is essentially the "manna from heaven" and there is little room for government to spur innovation, other than getting out of the way to deter it. This is why the U.S. government does not have an explicit national framework for innovation promotion for many commercial areas. Much of the role of the U.S. government for innovation is related only to the federal government missions, especially about defense, space, health, and energy. This limits the government-led proactive steps to explicitly support commercial innovations in relation to global competitiveness.

In contrast, the four Asian economies come from a different tradition that sees a more active role of government in promoting innovations. As Joe Studwell describes in *How Asia Works*, the only way "Asian Tigers" such as South Korea and Taiwan (and Japan earlier, and China now) could move up the industrial value chain was to form and implement national industrial strategies.[27] The contributions of smart industrial policies to the rapid economic growth of successful Asian economies such as Japan, South Korea, Singapore, Taiwan, and now China are clear.[28]

Although not all industry policies are successful, there is a significant body of research on the principles of designing effective industry policies, e.g., requiring the supported industry to have "skin in the game," insulating program decisions from politics, and not picking narrow technologies or single firms as winners. If industry policies comply with these principles, they have a high chance of success. A recent study by Juhász, Lane, and Rodrik (2023) suggests that it is no longer possible to dismiss industrial policy as ineffective or counter-productive.

However, whether the channels through which the industrial policies took effects for promoting economic growth are innovation (long-term growth source) or factor accumulation (transition growth source) may differ across the five economies. It depends on the stage of development and also on the country-specific nature of the development process. During the initial stage of industrialization, industrial policies focus on factor accumulation rather than innovation. This is true not only for the four Asian tiger economies but also for the U.S. When the U.S. economy went through the initial stage of industrial transformation, the U.S. government implemented strong industrial policies following the Hamiltonian spirit of active interventions and planning for nation-building, which gradually phased out as the U.S. market economy got matured. The industrial policies of Japan, Korea, and Taiwan today look quite different from what they did 20 to 30 years ago. The first-stage industry policies are usually directive and infrastructure-oriented, hence are related to factor accumulation, but later government plays the role of facilitator in cooperation with the private sector, focusing on innovations and productivity growth. From this perspective, the five economies show different degrees and different kinds of intervention but in a similar spectrum, and the roles of government for innovation appear to be different across the five economies. The roles of government are stronger and more directive in descending order of China, Taiwan, Japan, Korea, and the U.S. As usually happens in fast-catching-up emerging economies, the contents of the interventions are mixed between simple factor accumulation and innovations rather than gradually shifting from factor accumulation toward innovation. This is the case for current China, different from Taiwan, Korea, and Japan 20 to 30 years ago.

Furthermore, there are important caveats for China in interpreting the role of government because of two reasons: first, its political governance, and second, its size effect. First, given the ongoing reinforcement of the totalitarian governance in political and economic powers and the long desire for the revival of its global dominance, it is unclear if the explicit roles of government in promoting innovations will phase out in China as it happened in other Asian Tigers and also in the U.S. Under the natural course of things, this kind of Chinese government's tendency to maintain a firm grip on the innovation domain would harm Chinese innovations in the long run, because the sustainable source of new ideas is the private sector subject to free and fair competition.

The second aspect that makes the Chinese role of government for national innovations is its population size of 1.4 billion, seven-fold larger than the combined population of Japan, Korea, and Taiwan. This sheer size effect has allowed China to add new tools of policy intervention that the other Asian Tigers did not have during the stages of their industrialization: controlling access to its huge market as a cudgel to demand concessions from foreign exporting firms, and influence to manipulate global standards of technology development. These policy tools based on the size effect of China generate externalities on the economies outside China in various dimensions including innovation promotion, hence the need for the national innovation systems of the economies outside China to properly respond to such externalities.

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Chapter 3

The United States

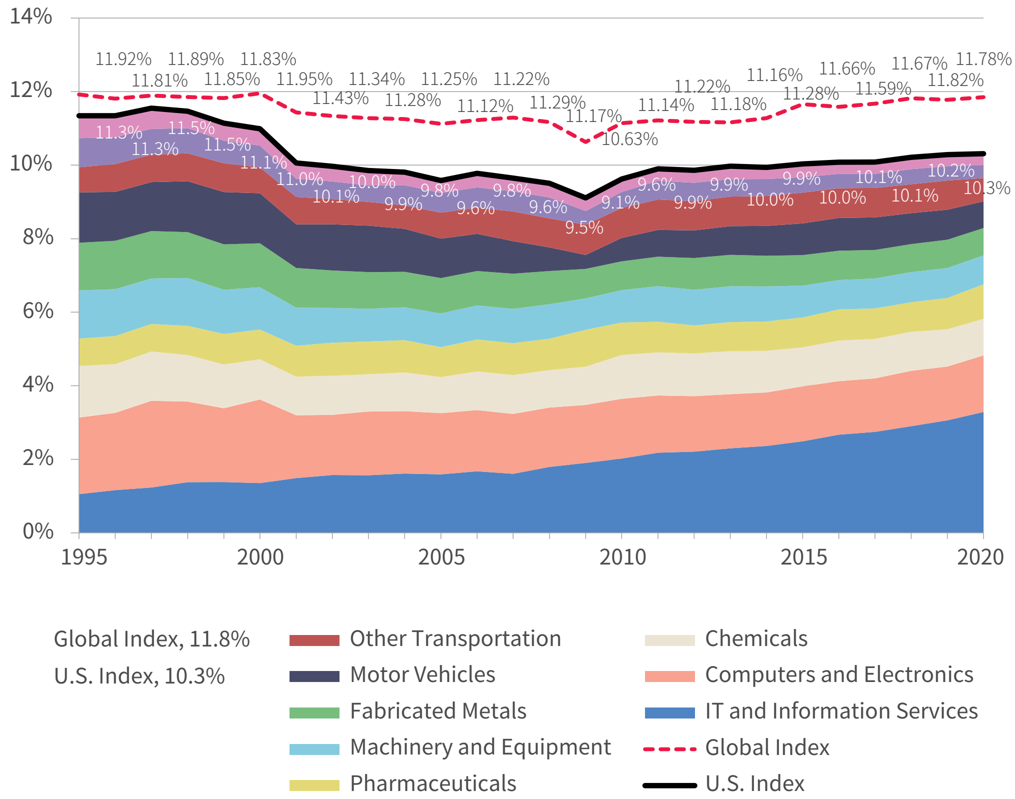
Robert D. ATKINSON

In the post-war period, the United States developed the world's most effective national innovation system. It was not called that—indeed it is referred to as the "hidden developmental state"—but through a set of policies, and most importantly, vast government investment in R&D, most of it focused on maintaining a technological and military advantage over the Soviet Union, the United States became the clear leader in technology. But the fall of the Soviet Union meant that policymakers no longer felt an urgency and presided over the gradual and inexorable shrinking of this once preeminent system. The rise of the ideology of market fundamentalism—which deeply influences Washington economic thinking—saw this shift not as a problem but a solution, as markets—not government—should be privileged. As such, the U.S. national innovation system today is in need of thorough rejuvenation. Fortunately, as reflected by the growing realization of the China technology challenge and the resultant recent bipartisan congressional advanced technology legislation, there is a growing awareness of this need.

1. U.S. Advanced Industry Performance

Ten leading advanced industries together accounted for 10.3 percent of the U.S. economy in 2020—13 percent less than the global average of 11.8 percent. (See Figure 3.1) And that share fell from 1995 to the end of the 2000s, and has slowly risen since, although all that rebound has been in one sector: information and communication services. Leaving out this sector, U.S. output fell from 7.6 percent of the U.S. economy in 2010 to 7 percent in 2020.

Figure 3.1. **Hamilton Index industries' shares of the U.S. economy**



In terms of overall global share, U.S. output fell from a peak of 27.8 percent in 2000 to 21.5 percent in 2020. However, from 2011 to 2020, that share increased from a low of 18.6 percent, but this was all because of IT services growth. When leaving out this sector, the U.S. global share peaked in 2000 (at 27.6 percent), just as offshoring to China began to take off. However, after reaching a low of 16.9 percent in 2016, it gradually grew to 18.0 percent in 2020. (See Figure 3.2.) As such, the U.S. strength in IT services masks a real, structural weakness in advanced manufacturing. Advanced industry production minus IT and other services fell from roughly 28 percent in the early 2000s to around 18 percent by the end of the 2010s.

Figure 3.2. **America's global share with and without IT**

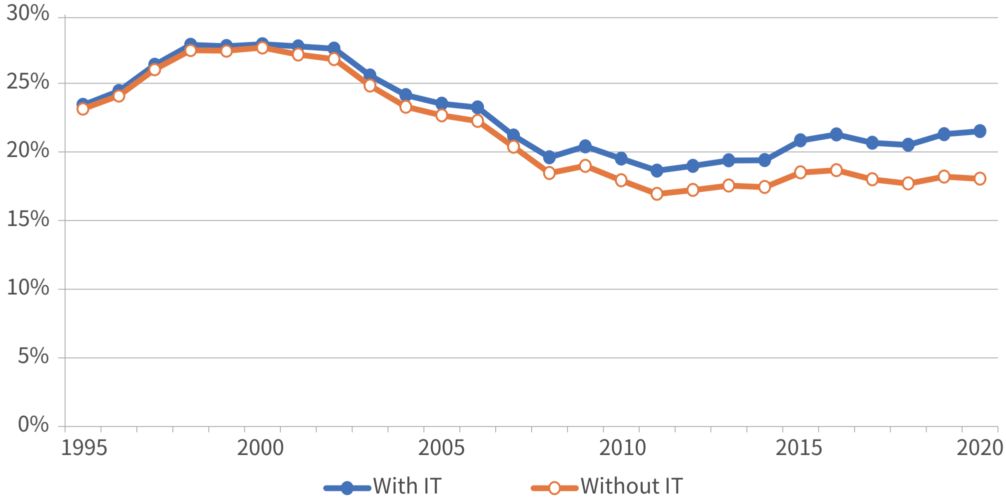
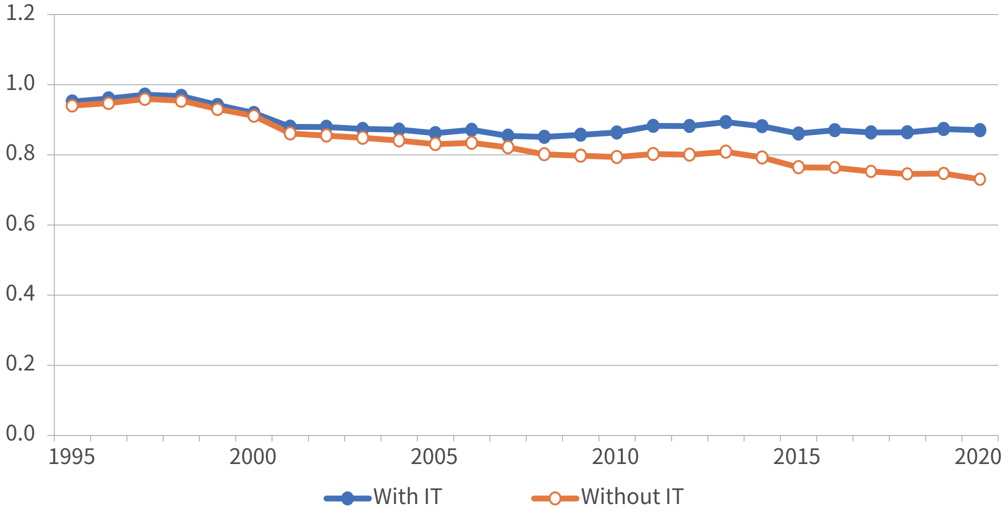
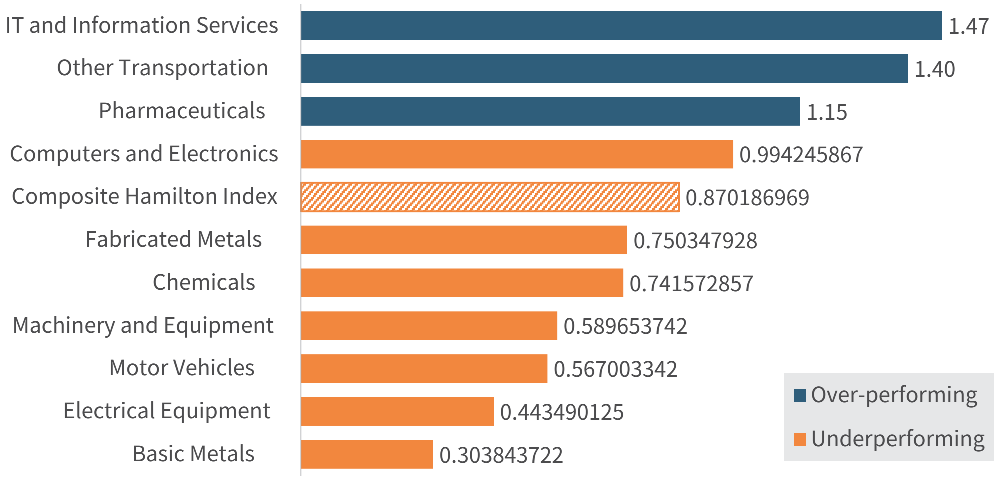


Figure 3.3. **America's LQ with and without IT**



The United States has just three industries with an LQ of above 1: IT and information services (1.47); other transportation (1.40), which reflects U.S. strength in aerospace; and pharmaceuticals (1.15). The computer and electronics industry is essentially at 1 (0.99). The other sectors are all 0.75 or below.

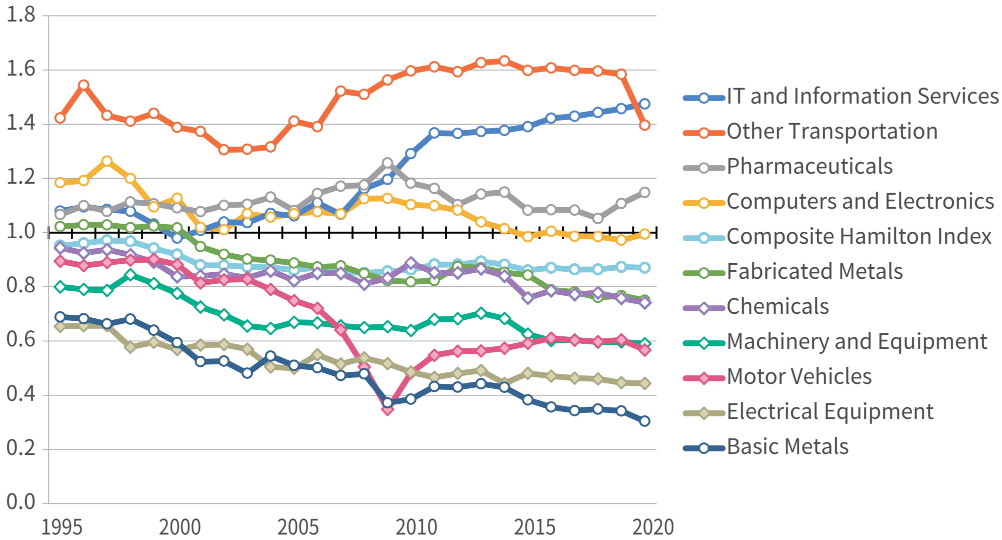
Figure 3.4. America's relative performance in Hamilton Index industries (2020 LQ)



Only two industries saw an increase in their global LQ since 2008: IT and other information services (+27 percent) and motor vehicles (+12 percent). The former is because of the strength in the U.S. software sector and the light-touch regulatory system adopted by the United States (compared with the more heavily regulated EU system and the more hardware-focused East Asian system). With the across-the-board systematic attacks on large IT firms and a push by the federal government to restrict and regulate the industry, strength in America's leading advanced industry sector is under threat. The United States also gained in motor vehicles, but that was only because of the beginning of the steep cyclical decline in 2008. Its 2020 LQ is below 2007 levels.

In contrast, the United States has significantly deindustrialized since 1995 in other industries, including basic metals (-56 percent); motor vehicles (-37 percent); electrical equipment (-32 percent); fabricated metals (-27 percent), machinery and equipment (-26 percent), and chemicals (-21 percent). Computers and electronics, which include semiconductors, saw a 16 percent decline in LQ. Despite the fracking revolution and the decline in natural gas prices, the U.S. chemical industry continued to decline, with its LQ falling from 0.89 in 2010 to 0.74 in 2020.

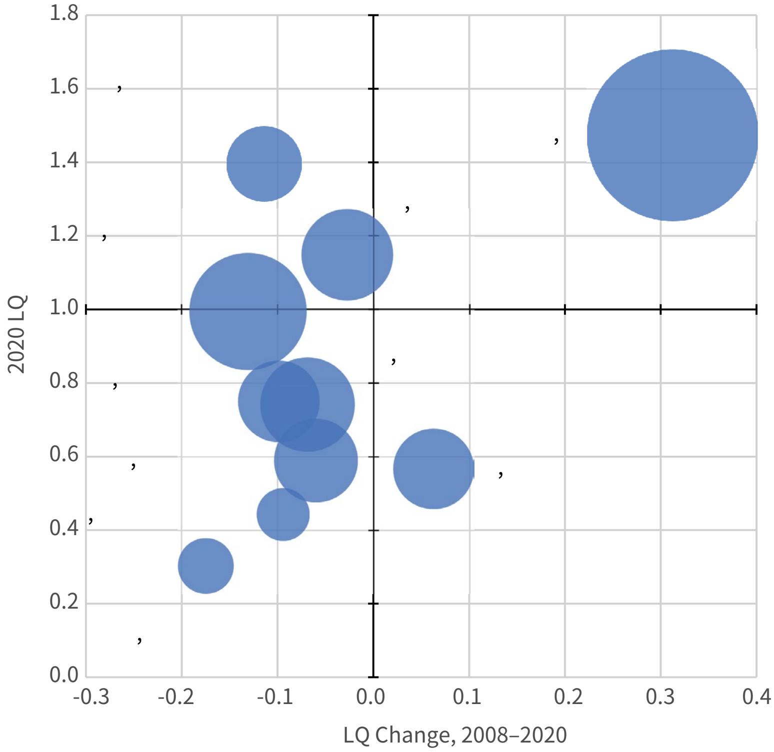
Figure 3.5. America's relative historical performance in Hamilton Index industries (LQ trends)



The United States had only one industry in the "strong growth quadrant" (an LQ above 1 and an increase in LQ since 1995): IT and information services. (See Figure 3.6) Fortunately, it is also America's largest advanced industry sector. The United States has two sectors in the "strong declining" quadrant: transportation and pharmaceuticals. The pharmaceutical industry is strong because of the optimal mix of policy (strong patent protection, robust National Institutes of Health funding, effective drug approval, and reasonable drug pricing policies). All those factors are now under threat from federal policy. It also is declining because of the movement of drug production offshore. Other transportation is high but has been falling in part due to the challenge of Europe's Airbus and, in the future, China's unfair COMAC competition.

The motor vehicles industry is in the "weak, growing" quadrant, but that is only because 2008 was such a weak year for production. If we used 2007 as the base year, it would be in the weak-declining sector, where the rest of the sectors are. Except for motor vehicles, all sectors are facing intensive competition from China. Overall, the U.S. momentum score is 116, lower than the average for the 40 nations.

Figure 3.6. America's net performance since 2008 (scaled to 2020 output)



The United States national innovation system has evolved over the last two centuries, yet retains many threads, including America's entrepreneurial and market-based system, coupled with mission-oriented (especially national defense) support. As new technology systems evolve and the United States faces robust technology competitors, the U.S. system will need to evolve.

2. History and Evolution of America's NIS

In order to better understand the U.S. innovation system, it's worth examining the history of the United States in terms of innovation and innovation policy. Clearly, this brief overview cannot do justice to this enormously complex topic, but it can provide a basic outline.[1]

For the nation's first half-century, there was a long policy conflict between Jeffersonians who advocated for a minimal role for the federal government and idealized a rural and small craftsperson economy, and Hamiltonians who advocated for a stronger role for the government in order to industrialize. The tension was never resolved, but the Hamiltonians did make progress, including funding internal improvements (canals and roadways) and supporting industrialization through tariffs and government expenditures for weapons development, such as the formation of the Springfield Armory in 1777. Since the founding of the Republic, the federal government had a robust patent system embedded in the Constitution.

The Civil War represented the transition to a second national innovation system. With the agrarian South no longer represented in Congress, the path was paved for significant legislation to move the nation forward technologically, including the building of the intercontinental railroad, and the passage of the National Bank Act. Congress also created a system of research-based land grant colleges through the Morrill Act. Funding for agricultural research helped power agricultural productivity, which freed up tens of millions of farm workers to power America's growing factories, and helped create larger markets for industrial producers. In addition, with the weakening of the Democratic South (an agrarian region that opposed high tariffs on industrial goods), Congress expanded tariff protection for manufactured goods, which did not really end until after WWII.

Still, for the first 125 years after its founding, the United States was not at the global technology frontier—that advantage was held by select European nations, first the United Kingdom and then Germany. However, with the emergence of the steel-based industrial revolution of the late 1890s, the United States joined the ranks of world leaders, producing a host of leading-edge innovations. As business historian Alfred Chandler showed, the large American market enabled U.S. firms to successfully enter new mass production industries, such as chemicals, steel, and meat processing, and later autos, aviation, and electronics.[2] Because scale mattered so much to innovation and firm competitiveness, U.S. firms such as DuPont, Ford, GE, GM, Kodak, Swift, Standard Oil, and others became global leaders.

Scale helped, but the United States had other advantages. One was the "greenfield" nature of development. Unlike Europe, which had to overcome a pre-industrial craft-based system, the American economic canvass was newer, enabling new forms of industrial development to be more easily established. Another advantage was the unrelenting commercial nature of the American culture and system, where commercial success was valued above all else. As President Calvin Coolidge famously stated, "The business of America is business."

Moreover, policy to spur competition—through the Sherman Antitrust Act of 1890 and the Clayton Antitrust Act of 1914—was used to ensure firms had the incentive to continue to innovate. Although unlike Europe, whose antitrust laws enabled cartels, U.S. laws did not encourage firms to cooperate not through "trusts" but through mergers, enabling very large U.S. firms to succeed in global markets.

And as Charles Morris's *The Dawn of Innovation: The First American Industrial Revolution* shows, wars (including the War of 1812, the Civil War, and WWI) energized government-funded technology and industrial development, including helping metal-industry innovation such as precision metal measurement and interchangeable parts. During WWI, the government played a key role in advancing aviation and also electronics, with the Secretary of the Navy, Franklin Roosevelt, taking the lead in the formation of the Radio Corporation of America (RCA). Notwithstanding these factors, by and large, America's industrial innovation prior to WWII was principally powered by private inventors and firms.

This changed dramatically after WWII with the emergence of a more science-based system of innovation (inspired in part by Vannevar Bush, director of the U.S. Office of Scientific Research and Development during WWII) which would become dominated by large firms and the federal government. The establishment—initially in the Great Depression and then after the war—of large, centralized corporate R&D laboratories helped drive innovation in an array of industries, including electronics, pharmaceuticals, and aerospace. On top of this, the massive federal support for science and technology in WWII helped develop the "arsenal of democracy" the Allies used to beat back the Axis powers' threat.

Prior to WWII, the U.S. innovation system was largely based on achieving national greatness and catching up to Europe, including by copying. With WWII and the subsequent rise of the Soviet threat, the federal government constructed a new innovation system, based on now becoming the innovation leader and expanding that lead. The massive expenditures on weaponry and R&D in World War II positioned the United States as the global leader in a host of advanced industries, including aerospace, electronics, machine tools, and others. The response to the Soviet threat—exemplified by Sputnik—helped cement America's technology leadership. By the early 1960s, the federal government invested more in R&D than every other foreign government and business combined.

This strong federal role continued after the war, with substantial funding of a system of national laboratories and significantly increased funding of research universities. In 1945, the Army published a policy affirming the need for civilian scientific contributions in military planning and weapons production. In 1946, Congress created the Atomic Energy Commission and a system of national laboratories. The Department of Defense (DOD) established the first FFRDC (RAND) and University Affiliated Research Centers in 1947. Congress passed the Defense Production Act of 1950 and also created the National Science Foundation (NSF). Eisenhower pressed for the passage of the Interstate Highway Act. The Defense Advanced Research Projects Agency (DARPA) and NASA were established in 1958. And it provided the critical, although usually overlooked, inputs to America's key technology hubs, including Boston's Route 128 and Silicon Valley. Indeed, even in the late 1980s, Silicon Valley's Santa Clara received more DOD prime contract award dollars per capita than any other county.

Federal funding of research helped drive innovation and played a key role in enabling U.S. leadership in a host of industries, including software, hardware, aviation, and biotechnology. This funding enabled the development of a host of critical technologies we enjoy today, including jet aircraft, the Internet, GPS, LED lighting, microwaves, radar, networked computers, wireless communications, and many others.[3] For the most part, this research was funded through mission-based agencies seeking to accomplish a particular federal mission (e.g., Defense, Health, Energy) and through a system of peer-reviewed basic research funding at universities.

In fact, the explicit promotion of innovation and productivity as an economic goal was largely ignored and even rejected through most of the post-war period. To be sure, there were occasional efforts during the Kennedy, Johnson, and Nixon administrations, but these were small-scale and largely short-lived. The first major post-war federal effort to explicitly support industrial innovation was made by the Kennedy administration in 1963, with its proposal for a Civilian Industrial Technology Program (CITP). The administration proposed CITP to help balance the overriding focus of federal R&D on defense and space exploration, both of which had increased as the United States sought to counter the Soviet Union in the Cold War.[4] CITP was to provide funding to universities to do research helping innovation in sectors thought to help society, such as coal production, housing, and textiles. But despite the administration's efforts to launch the program, Congress did not approve it, in part because of industry opposition that feared disruptive technologies. For example, the cement industry opposed the program because it feared that innovation in housing technology might reduce the need for cement in construction.

Two years later, the Johnson administration was able to get a redesigned effort through Congress, but only after making a number of changes. The new program, the State Technical Services program, was to fund university-based technology extension centers in the states that would work with small and mid-sized companies to help them better utilize new technologies. But despite the program's success, the Nixon administration eliminated it, largely on the grounds that this was an inappropriate federal intervention into the economy. However, the Nixon administration proposed its own initiative, the new Technology Opportunities Program, again to support technology in solving pressing social challenges, such as developing high-speed rail and curing certain medical diseases. But again, the program was not funded by Congress.

These attempts by the federal government to explicitly support commercial innovation were at best made in fits and starts, and never really got off the ground. Moreover, they were not guided by any overriding vision or mission, unlike the government's efforts to develop defense and space technology, which were motivated by the need to respond to the Soviet threat. And they certainly were not linked to overall economic policy, which remained focused principally on reducing business-cycle downturns, and depending on the political party in power, reducing poverty.

This system began to gradually change in the late 1970s with the emergence of competitiveness challenges from nations such as Japan and Germany. It was with the election of President Jimmy Carter in 1976 that the federal government began to focus in a more serious way on the promotion of technology, innovation, and competitiveness. The motivation for this was the major recession of 1974 (the worst since the Great Depression), the shift in the U.S. balance of trade from one of surplus to one of deficit, and the growing recognition that nations such as France, Germany, and Japan now posed a serious competitiveness challenge to U.S. industry.

These efforts were followed up by efforts by Congress and the Reagan and Bush I administrations. Indeed, policymakers responded with a host of policy innovations, including the passage of the Stevenson-Wydler Act, the Bayh-Dole Act, the National Technology Transfer Act, and the Omnibus Trade and Competitiveness Act. They created a long list of alphabet-soup programs to boost innovation, including SBIR (Small Business Innovation Research), NTIS (National Technical Information Service—expanded), SBIC (Small Business Investment Company—reformed), MEP (Manufacturing Extension Partnership), and CRADAs (cooperative research and development agreements). They put in place the R&D tax credit and lowered capital gains and corporate tax rates. They created a host of new collaborative research ventures, including SEMATECH, NSF Science and Technology Centers and Engineering Research Centers, and the National Institute of Standards and Technology (NIST) Advanced Technology Program. And they put in place the Baldridge Quality Award and the National Technology Medal.

Moreover, it wasn't just Washington that acted. Most of the 50 states transformed their practice of economic development to at least include the practice of technology-led economic development. Many realized that R&D and innovation were drivers of the New Economy, and state economies prosper when they maintain a healthy research base closely linked to commercialization of technology. For example, under the leadership of Governor Richard Thornburgh, Pennsylvania established the Ben Franklin Partnership Program that provides matching grants primarily to small and medium-sized firms to work collaboratively with Pennsylvania universities.

But by the time Bill Clinton was elected in 1992, America's competitiveness challenge appeared to be receding. Japan was beginning to face its own problems, in part stemming from the popping of its property bubble and the increasing value of the yen. And Europe was preoccupied with its internal market integration efforts. Moreover, with the rise of Silicon Valley as a technology powerhouse, and of the Internet revolution and companies such as Apple, Cisco, IBM, Intel, Microsoft, and Oracle, America appeared to be back on top, at least when it came to innovation. And most importantly, the collapse of the Soviet Union eliminated what had been a principal motivation for bipartisan cooperation and activity to ensure the United States was the world's leading technology power. Once that was gone, other priorities such as balancing the budget and increasing spending on social services soon trumped advancing national innovation. As such, federal spending on innovation policy gradually shrank year after year, to the point where today as a share of gross domestic product (GDP) it is where it was before the Russian Sputnik satellite.

On top of that, information technology entered into a new phase, with more powerful microprocessors, the wide-scale deployment of fast broadband telecommunications networks, and the rise of Web 2.0 social network platforms. As a result, it became clear to many policymakers that IT (or ICT) was now a key driver of growth and competitiveness, and that effective economic policy now had to get IT policy right.

Toward that end, the Bush II administration and Congress undertook a number of initiatives. Building on the Clinton administration's Internet Governance Principles, which argued that government should take a light touch toward regulating the Internet, the Bush administration took a number of steps to spur IT innovation, including deregulating broadband telecommunications (now that most American homes had access to at least two broadband "pipes"— cable and DSL), freeing up radio spectrum for wireless broadband, taking a light touch with respect to regulating online privacy, and using IT to transform government itself (e-government). The fact that the United States was the clear leader in IT, including the emerging Internet economy, led many to believe all was well.

But while much of IT was thriving, U.S. industrial competitiveness was not. The United States lost over one-third of its manufacturing jobs in the 2000s, with the majority lost due to falling international competitiveness, not superior productivity.[5] The United States went from running a trade surplus in high-technology products in 2000 to around a $100 billion deficit a decade later. While the United States used to produce significant amounts of electronic products, including computers, much of that went to China. In fact, by 2017, the trade deficit with China in electronic products was $184 billion.[6]

In any case, the state of U.S. industrial innovation and competitiveness has gained renewed attention after the losses of the 2000s, the Great Recession, and the emergence of robust new technological competitors—especially China. Because of this, the Obama administration proposed a number of initiatives, including the establishment of a National Network of Manufacturing Innovation (three centers have already been announced); an expansion in the research and experimentation (R&E) tax credit; increased funding for science agencies (including NSF, NIST, and Department of Energy (DOE)); policies to expand the number of STEM graduates; patent reform; and increased efforts to limit unfair foreign "innovation mercantilist" policies, among others. Congress has also introduced a variety of similar measures."

The Trump administration brought a new approach to dealing with the China challenge, but largely eschewed any formal technology policy, actually proposing cuts in overall federal R&D and to specific manufacturing technology support programs.[7]

More recently, bipartisan efforts in Congress have led to the introduction of a number of major technology competitiveness bills to respond to the China technology challenge, including the CHIPS and Science Act to provide incentives for building semiconductor fabs and increasing scientific and engineering research. In addition, clean energy has emerged, especially from Democrats, as a key component of a national innovation institute. However, it is important to not read too much into these, as the CHIPS Act was largely driven by defense concerns over a possible Chinese takeover of Taiwan, and the Science Act component ended up getting relatively little in new funding. Moreover, the Biden administration's main domestic policy agenda is not technology and innovation promotion, but increased economic equity and promotion of the green transition.

3. Elements of the U.S. National Innovation System

There are three elements of a national innovation system: the business environment, the regulatory environment, and the innovation policy environment. This section describes each, and the U.S. performance in each.

3.1. Business Environment

The business environment consists of three broad factors: market and firm structure and behavior; the system for financing business; and related social and cultural factors affecting how the business operates.

3.1.1. Market and Firm Structure and Behavior

Managerial Talent

When it comes to managerial talent, it appears the United States is the world leader, and this factor has played a role in explaining past U.S. innovation leadership. As Professor John Van Reenen and colleagues have shown, "[When] it comes to overall management, American firms outperform all others."[8] In part, this comes from environmental factors that force better management: more competition and more flexible labor markets. But it may also come from the fact that the United States developed the discipline of management (in the 1950s) and perfected it through its extensive system of business schools at universities.

Time Horizon and Risk Appetite of Firms

Despite the high quality of many U.S. managers, they increasingly find themselves in firms buffeted by pressures for short-term performance, which in turn reduces their ability to invest for the long term. For example, in a 2004 survey of more than four hundred U.S. executives, over 80 percent indicated that they would decrease discretionary spending in areas such as R&D, advertising, maintenance, and hiring in order to meet short-term earnings targets; and more than 50 percent said they would delay new projects, even if it meant sacrifices in value creation.[9] One study by the CFA Institute finds that while some progress has been made in the last 15 years, too many companies are still too short-term in their orientation.[10] This focus on maximizing short-term returns means companies are effective in reducing waste and pulling the plug on poor investments. But at the same time, this pressure to achieve short-term profits all too often has meant sacrificing long-term investment, which is the majority of investment in innovation. As the Business Roundtable, the leading trade association for large American businesses, reported, "[T]he obsession with short-term results by investors, asset management firms, and corporate managers collectively leads to the unintended consequences of destroying long-term value, decreasing market efficiency, reducing investment returns, and impeding efforts to strengthen corporate governance."[11]

ICT Adoption

U.S. firms are among the world leaders in the adoption of ICT (e.g., hardware and software). In 2000, U.S. firms invested more as a share of sales in capital investment in hardware, software, and telecommunications than only one other Organization for Economic Cooperation and Development (OECD) nation (Sweden).[12] But that lead has shrunk. OECD reported that in 2015, seven other nations saw more business investment in software and IT equipment as a share of GDP than the United States.

However, in some areas, U.S. performance is better.[13] The United States ranks fourth in the share of businesses using cloud computing services.[14] And Van Reenan and Bloom found that U.S. firms appear to get more benefit out of IT investment than many other countries' firms. In part, this is because U.S. firms are more willing to use IT to fundamentally restructure production processes.[15]

WORKFORCE TALENT

The U.S. workforce system faces a number of challenges. A not insignificant share of workers face disabilities and disorders. In 2015 almost 10 percent of full-time workers faced a substance abuse disorder.[16] In 2013, 28 percent of U.S. workers were obese, a condition the NIH finds negatively affects productivity.[17] Persistent skill gaps exist for many occupations.[18] The United States ranks 70th in graduates enrolled in science and engineering out of xx nations and 24th in PISA scores in reading, math and science.[19] And these skill gaps are not just among workers with less education. One in five employed adults with a bachelor's degree lacks important skills in literacy, with one in three falling below proficient levels in numeracy.[20] As long-time education expert Marc Tucker writes "We now have the worst-educated workforce in the industrialized world."[21]

3.1.2. Business Financing System

Venture and Risk Capital

With the establishment of the American Research and Development Corporation in 1946, the United States pioneered the venture capital industry—and remains a leader. Hundreds of private venture capital firms across the nation analyze and fund investment opportunities. The industry does more than invest funds; it also helps with key management functions such as serving on boards and advising on business strategy.

Over the last decade or so, the amount of venture investing has grown significantly, with the value of deal investment growing 4.6 times from 2006 to 2019, and the number of deals growing 3.6 times. Moreover, angel and seed funding deals grew 11 times to 5,207.[22] However, most venture capital placements are concentrated in a few states (e.g., California and Massachusetts, and to a lesser extent Colorado and Washington). However, from 2006 to 2019, venture capital funding grew slightly slower in New England and the West Coast than in the rest of the nation.

There is also a robust "angel capital" system in the United States made up of private individuals of high net worth who invest money in entrepreneurial, high-growth companies.[23]

Some state governments have also established programs to help with venture funding, particularly to smaller and earlier-stage start-ups. Some have also created angel capital networks to help private funders better coordinate their efforts and find deals. And the federal government, through the Small Business Administration's Small Business

Investment Company, provides capital subsidies to some private-sector venture firms, while the SBIR program provides modest research grants to small firms.[24]

Firm Finance (Debt and Equity)

Firms in the United States have access to a wide array of financing sources, the vast majority of which are provided by the private sector. While the initial public offering (IPO) market is smaller than it has been in the past, many growth-oriented innovation-based firms are able to obtain capital through IPO placements. In 2019, firms raised around $39 billion through IPOs, down from the boom years of the late 1990s, but generally greater than a decade ago.[25] Small, high-growth start-up firms also use acquisitions by larger firms as an "exit" strategy, although some in the antimonopoly camp have recently argued that large firms should be limited in their ability to purchase start-ups.

Government financing for firms is quite limited. Existing firms can raise additional money on highly traded and liquid equities markets. And corporate debt, either through bonds or loans, is widely available. At the federal level, the Small Business Administration provides some direct and indirect lending to small firms, but this is not targeted to innovation-based firms or firms in traded sectors—and in fact, the significant majority goes to local-serving industries such as dry cleaners, restaurants, and liquor stores. And many state governments provide modest financing for industrial expansion and early-stage firms.

3.1.3. Cultural Factors

As scholars such as Francis Fukuyama, Raquel Fernandez, Lawrence Harrison, and Samuel Huntington have shown, cultural factors such as trust, group orientation, and risk-taking have impacts on innovation and growth.[26]

Nature of Customer Demand

As Michael Porter's work on competitive advantage indicates, nations with demanding consumers are in a better position because it puts pressure on firms to innovate and be more efficient.[27] While there is little good data on this, it appears American consumers are more demanding than those in many other nations. Moreover, thanks to the Internet, and applications such as Yelp and others, most U.S. consumers have immediate access to a wealth of information about businesses. We see this in terms of comparing U.S. industries to ones in Europe. For example, standard business traveler hotel quality in the United States appears to be far superior to Europe, in part because American consumers demand higher quality.[28] Columbia professor Amar Bhidé has also argued that the "venturesome consumption" nature of American consumers—that is, their eagerness to be early adopters of and experiment with new products and technologies—has played a role in supporting U.S. innovation success.[29] For example, a Microsoft survey found that 54 percent of customers in the United Kingdom, 53 percent in Japan, and 58 percent in Germany don't think their feedback to businesses is taken seriously, while only 45 percent of Americans think that way.[30]

Risk Taking and Entrepreneurship

The United States has long been seen as having a culture of "Yankee ingenuity," meaning a deep-seated interest in tinkering, inventing, and making things better. At the same time, in part because the United States is a nation of immigrants, who by definition took a major risk to move from their native country, the United States has a strong culture of risk-taking and entrepreneurship. Combine that with a distinct culture of individualism, and this makes it easier for people—whether they are Steve Jobs or a workers on the shop floor—to question established ways of doing things.[31] Moreover, unlike many other nations, failure in starting a new business does not doom a professional career. (In fact, it's been said that some Silicon Valley venture capital firms don't want to see entrepreneurs' business plans until they're on their third start-up.) And compared with most other nations, Americans are more willing to take risks in terms of financing and see the potential benefits as higher.[32]

Attitudes Toward Science and Technology

For much of its history, American culture was characterized by a general belief in the inevitability of social and economic progress. Historian Merritt Roe Smith discussed in a sampling of books from the period of the 1860s to the early 1900s with titles such as *Eighty Years of Progress*, *Men of Progress*; *Triumphs and Wonders of the 19th Century*, *The Progressive Ages or Triumphs of Science*, *The Marvels of Modern Mechanism*, *Our Wonderful Progress*, *The Wonder Book of Knowledge*, and *Modern Wonder Workers.*[33] As economist Benjamin Anderson wrote in the 1930s, "[O]n no account must we retard or interfere with the most rapid utilization of new inventions."[34] While America still largely tilts toward innovation, the anti-innovation forces in U.S. culture are stronger today than ever in American history. Whether it is fears of job loss from automation, privacy loss from the Internet, or environmental damage from nano-tech or biotech, anti-technology forces—in the media, "public interest" groups, and the public at large—continue to gain influence, making it harder for the U.S. economy to press ahead with innovation, and making it more likely to adopt precautionary principle-based regulations, if not outright technology bans.[35] Case in point: When MIT's project on the future of work calls for the federal government to "tax robots" to slow down automation, it's clear there has been a major shift in the American political economy toward innovation.[36]

Collaborative Culture

While innovation is about competition, it's also about "coopetition" and cooperation—in other words, groups working together to drive innovation. This has become more important to enabling innovation, especially as innovation has become more challenging, with more organizations embracing open innovation. As Fred Block found, the nature of the U.S. innovation system became more collaborative.[37] Using a sample of innovations recognized by *R&D Magazine* as being among the top 100 innovations of the year from the 1970s to the 2000s, they find that while in the 1970s almost all winners came from corporations acting on their own, in the 2000s, over two-thirds of the winners came from partnerships involving business and government, including federal labs and federally funded university research. The culture of collaboration in places such as Silicon Valley and Boston's Route 128 is one of the keys to their success. Likewise, the ability of some leading U.S. universities to work cooperatively with industry has been key to driving regional innovation hubs and clusters. These collaborative learning systems, especially in clusters, are supported in part by strong IP protections—people aren't afraid that if they talk and share, they will lose proprietary IP.

Time Horizon and Willingness to Invest in the Future

For much of American history, Americans have been willing to sacrifice current consumption for future income by supporting high levels of private and public investment. That sacrifice paid off handsomely in more innovation and productivity. Over the last three decades, this has become more challenging, as the focus of most voters and the overall political system has shifted toward current consumption, either in the form or lower taxes or greater spending. In the 1960s, when federal support for R&D amounted to 1.75 percent of GDP, this meant Americans were willing to invest 2.8 percent of their income in government R&D.[38] Today, with per capita incomes more than three times higher in real dollars, Americans are only willing to invest just 0.87 percent of their income in government R&D (just 17 percent of the 1960s level).

3.2. Trade, Tax, and Regulatory Environment

While the business environment plays the key role in determining innovation success, government policy plays a powerful enabling (or detracting) role, particularly through the broad areas of trade, tax, and regulatory policy that shapes the innovation environment.

3.2.1. Regulatory Environment

Industry Structure and the Nature of Competition

Generally, the United States has embraced an approach to competition and competition policy based on maximizing consumer welfare. In contrast to the "ordoliberal" tradition of EU antitrust policy which embraces both economic and social goals, and in particular focuses on preserving competition for its own sake, the U.S. approach until recently was oriented to maximizing consumer—as opposed to producer—welfare, and was focused on anti-competitive behavior more than on market power per se.[39] However, in the last several years, there has been an increasing push from "neo-Brandeisians" for a wholesale shift in U.S. antitrust policy to focus more on limiting firm size, regardless of conduct, and on limiting competitive effects on other businesses, especially small business.[40] The recent majority report from the House Judiciary Committee on digital maker competition reflects this trend.[41]

While there is considerable disagreement about exactly where antitrust policy should be on the continuum of more or less competition, one can make the case, as Robert Atkinson and Michael Lind do in *Big is Beautiful: Debunking the Myth of Small Business* that U.S. antitrust policy has been too stringent, limiting the emergence of the kind of scale needed to win in global competition, and too focused on consumer welfare rather than overall economic welfare.[42]

Moreover, in comparison with many other nations and regions, especially Europe, the U.S. NIS erects relatively few barriers to entry for firms to break into existing markets, thus ensuring robust competition and the constant threat of "Schumpeterian" creative destruction. We have seen this in industries as diverse as financial services, energy production, and transportation. In addition, the U.S. system attempts to create a level playing field with e-commerce competitors, enabling new entrants to disrupt existing markets and business for the advantage of the consumer. However, entrenched interests in industries such as real estate, car sales, taxi services, hotels, legal services, and others continue to seek to use laws and regulations to limit competition.

Regulatory System for Entrepreneurship

Academic research shows that delays caused by entry regulations are associated with lower rates of firm entry.[43] In 2020, the United States ranked sixth on the World Bank Index of ease of starting a business, behind nations including Denmark, Korea, New Zealand, and Singapore.[44] This is down from number 1 in 2004.[45] Moreover, it is not only relatively easy to start a new business, but it is also easy to close one or lay off workers, at least in the non-unionized, non-governmental share of the economy.[46] The latter is important, for if entrepreneurs cannot easily close or downsize businesses, and if investors cannot obtain reasonable capital recovery rates, the incentives for entrepreneurship are reduced.[47]

Role and Form of Regulation

The U.S. system of regulations, many of which affect innovation, begins with Congress passing legislation and sometimes requiring executive branch agencies to promulgate regulations. These agencies go through an extensive public notice and comment period in which individuals and organizations can submit written comments that the agencies are required to review. In addition, the Office of Information and Regulatory Affairs (OIRA) within the White House Office of Management and Budget also conducts cost-benefit reviews of some proposed regulations, particularly those with high expected costs. To the extent OIRA finds a “significant” federal regulation inconsistent with its cost-benefit analysis, it can return the regulation to the promulgating agency (which can then revise or withdraw it). Although OIRA’s analysis does not always trump that of the agency, it does dominate. And of course, if agencies do not change their regulatory decision, Congress can also act and change the law. And this process is generally quite transparent. For example, the Clinton administration inserted greater transparency into the OIRA review process by requiring, inter alia, public disclosure of all communications between OIRA personnel and individuals not employed by the executive branch.

While regulation is not always performance based, in the last two decades, there has been a greater awareness among regulators of the importance of focusing regulations more on what the government wants to achieve, while leaving the means by which to achieve it up to the regulated entities. There is some recognition that this form of regulation is more efficient and spurs more innovation than regulation that prescribes the means.

However, it appears that the U.S. regulatory burden on innovation, both in extent and orientation, grew in the 2000s until the election of President Trump in 2016. Trump made it a key focus to reduce regulations in a wide array of areas. However, in areas such as agricultural biotech, AI, privacy, and others, the pressures for stronger regulation continue to grow. Moreover, most regulatory agency budgets have been cut or limited, making it harder for them to both modernize technologies and processes and expand staff so that they can respond quickly to firms seeking regulatory approval.

Transparency and Rule of Law

Regulations have less of a negative effect on innovation and growth when they are transparent and backed up by the rule of law so that they are consistently applied. This has generally been a strength of the U.S. system, which enjoys a well-developed, independent judiciary and a legislative framework (e.g., the Administrative Procedures Act) that works to hold government executive agencies accountable for obtaining public input and basing rules on evidence. However, the Trump administration has at times intervened—often through the president's "bully pulpit" of Twitter—to put pressure on companies and administration agencies to act in certain ways.

3.2.2. Tax, Trade, and Economic Policy

Macroeconomic Environment

Macroeconomic policies can provide an overall supportive policy for innovation. U.S. macroeconomic policy has been predicated on monetary stability, focused on limiting inflation. Some have argued that in its efforts to limit inflation the Federal Reserve Board has placed too little relative emphasis on full employment, especially since the late 1970s. At least since the 1980s, U.S. macroeconomic policy has relied principally on monetary policy, rather than fiscal policy, to adjust cyclical growth rates. But the 2008 American Recovery and Reinvestment Act and the 2020 COVID recovery packages suggest that fiscal policy tools may be relied upon more going forward, especially if Democrats gain more political power and Modern Monetary Theory gains adherents.[48] In addition, because of the overriding focus on consumer as opposed to producer welfare, as well as a belief that markets should determine prices, U.S. policy toward its currency (and that of other nations) is largely non-interventionist—and to the extent it is interventionist, it is to defend a strong dollar (which helps consumers but hurts most producers, especially in traded sectors).

Tax Policy

While the prevailing view about U.S. tax policy is that it should be neutral vis-à-vis various economic activities, the reality is that it is somewhat interventionist, sometimes for good policy reasons (e.g., R&D tax credit, accelerated depreciation, etc.), and other times because of special-interest pressures for particular tax provisions.[49] But most policymakers strive for a tax code that does not favor particular industries over others, even if it means some traded sectors exposed to international competition pay more than some non-traded sectors, and functions such as R&D with significant positive externalities are not adequately supported through the tax code.[50] After the tax reform act of 2018, the U.S. corporate tax rate was lowered from 35 percent to a more competitive rate of 21 percent.[51] Moreover, companies were allowed to expense for tax purposes investments made in capital equipment. However, the R&D credit is scheduled in 2022 to be reduced in value. This is on top of the fact that tax incentives for R&D are quite minimal compared with most OECD and BRIC (Brazil, Russia, India, and China) nations.[52] And the United States is also one of the very few nations that does not use a border-adjustable value added tax (VAT). Finally, there is increasing pressure from Democrats to raise taxes on business, especially corporations.

Trade Policy

For decades, U.S. trade policy was based on the belief that nations have a comparative advantage, and that an open and market-based trading system enables nations to achieve that advantage to the benefit of their consumers. This has led the United States to focus mostly on signing new trade agreements and being somewhat blasé toward trade enforcement. The Obama administration took some steps to remedy this, establishing an Interagency Trade Enforcement Center based on the belief that the benefits from trade will be less if other nations are not playing by the rules developed by the World Trade Organization. Nevertheless, funding for trade-enforcement efforts is relatively anemic, with the Office of the United States Trade Representative (USTR), Department of Commerce's (DOC) International Trade Administration (ITA), and State Department trade efforts significantly underfunded. The Trump administration's approach to trade has been fundamentally different than the prior Washington consensus, focused much more on bilateral (rather than multilateral) trade deals and being willing to take much tougher actions against foreign mercantilists, especially China. At least in rhetoric, the Trump administration has embraced a "results-oriented" approach to trade, rather than the prior "rules-based" one, and has used tariffs and the threat of tariffs to try to get desired results from foreign nations, especially China.

When it comes to trade promotion, the United States does very little compared with other nations. Funding authority for the Ex-Im Bank is limited compared with many other nations.[53] The same is true for the U.S. International Development Finance Corporation.[54]

Intellectual Property

The U.S. system of IP protection has its roots in the U.S. Constitution, which gives Congress the powers to promote "the progress of science and useful arts" by providing inventors with the limited but exclusive right to their discoveries. This applies to copyrights and patents, with trademarks similarly protected by Congress under the Commerce Clause (Article I, Section 8, Clause 3). The view then, as well as now, was that without reasonable protection for their IP, inventors and creators (e.g., individuals or companies) would innovate and create less. Patents and trademarks are governed by the U.S. Patent and Trademark Office (PTO) in DOC. Copyright is governed by the Librarian of Congress. And of course, Congress writes the laws under which these agencies must function, and mostly objective courts can rule on their decisions.

While there is some disagreement within the United States over exactly how strong IP protection should be, the differences are largely at the margin (with some arguing for slightly stronger protection and some for slightly weaker), or over particular issues regarding implementation (e.g., the debate over the proposed Stop Online Privacy Act (SOPA) legislation regarding how to identify and limit access to foreign infringing websites). Part of this overall debate has stemmed from the fact that there is some evidence that during the late 1990s and early 2000s, the U.S. Patent and Trademark office was perhaps too liberal in issuing patents, in part from a large patent backlog and from the development of novel applications (e.g., business methods patents). However, after passage of patent legislation that allowed an increased budget for the PTO, some of these problems appear to have receded. However, there is still a challenge from what some refer to as "patent trolls," a pejorative term used for a person or company that enforces its patents against one or more alleged infringers in a manner considered unduly aggressive or opportunistic, often with no intention to manufacture or market the product.

Standards

The U.S. commercial standards system (as opposed to standards for health, safety, and the environment) is characterized by a voluntary, consensus-based global system. By and large, the government itself does not get involved in picking particular industry standards. For example, in the dispute between HD and Blu-ray high-definition video players, the government did not pick a standard, instead letting cooperation and competition between industry and the emergence of consumer choice determine the winning standard. These standards processes are coordinated by industry trade associations and the American National Standards Institute (ANSI). ANSI facilitates the development of American National Standards (ANS) by accrediting the procedures of standards developing organizations (SDOs). These groups work cooperatively to develop voluntary national consensus standards. ANS are usually referred to as "open" standards. In this sense, "open" refers to a collaborative, balanced, and consensus-based approval process. The content of these standards may relate to products, processes, services, systems, or personnel. ANSI has served in its capacity as administrator and coordinator of the United States private-sector voluntary standardization system for more than 90 years. Initially funded by five engineering societies and three government agencies, ANSI remains a private, nonprofit membership organization supported by a diverse constituency of private- and public-sector organizations. ANSI and other SDOs also work with their counterparts around the world to develop voluntary, consensus-based global standards. While NIST is a federal laboratory, its work largely involves metrology (measurement), not private-sector standard setting.

3.3. Innovation Policy Environment

Innovation policy refers to policies specifically designed to spur technological innovation, as opposed to other policies that shape the overall environment for innovation. In general, U.S. innovation policy is less sophisticated and less well thought out than it is in many other nations. This is due in part to the dominance of the neoclassical economic consensus in the United States, which eschews these kinds of policies as inappropriate intervention into the economy, and in part because the United States has been the leader for so long, it does not believe it has to do much in response.[55]

The United States has a broad and diverse set of innovation actors. First, it has a broad array of firms of all sizes and ages engaged in innovation. At the government level, all 50 states have technology-based economic development programs, although compared to federal levels, their funding is modest. At the federal level, the United States is distinct in its lack of an agency dedicated to spurring commercial innovation and competitiveness. The closest agency to that role is the U.S. Department of Commerce and within it, the National Institute of Standards and Technology, but most of what the Department does has little to do with innovation (e.g., the Census Bureau).

3.3.1. Research and Technology

Support for Research in Universities and Research Labs/Research Institutes

The U.S. system for supporting scientific research is based on two fundamental aspects: support for mission-oriented research (e.g., defense and health) largely to federal labs, and support for basic, curiosity-directed research through university funding. The federal government financed approximately $129 billion of R&D activity in 2018.[56]

Relative to private-sector R&D funding trends, federal support for R&D has fallen substantially as a share of GDP from its high levels in the 1960s (during the Cold War and the race to the moon). To match levels of the 1980s as a share of GDP, funding would need to increase by about 80 percent, or $100 billion, per year.[57]

There have been occasional efforts to increase funding. In the late 1990s and early 2000s, funding for the National Institutes of Health (NIH) was doubled in order to accelerate health innovation, but as a share of GDP, NIH funding has since fallen by 25 percent.[58] In response to the war on terror and the Iraq and Afghanistan wars, federal funding for defense and homeland security R&D was significantly increased. And there was a temporary bump up in response to the economic recession in 2008. However, since then, and with the budget sequester, federal support for R&D has fallen.[59] Moreover, fiscal challenges facing the federal government may make future increases difficult. However, bipartisan legislation such as the Endless Frontiers Act, which would allocate $100 billion in funding to R&D, shows promise of reversing the slide.

Federal Labs

The United States funds a system of between 80 and 100 government research laboratories (some are government operated, while some are private contractor operated). The largest labs are funded by the departments of Defense, Energy, and Health. For the most part, research is funded to help agencies better achieve mission goals.[60] While not part of the National Labs system, the Defense Advanced Research Projects Agency (DARPA) and Advanced Research Projects Agency-Energy (ARPA-E) have also played an important role in the development of cutting-edge technologies initially designed to support core agency missions (e.g., defense or energy efficiency) that over time have yielded substantial technology spin-offs to the U.S. and global economy (e.g., the Internet, lasers, etc.). More recently, Congress established ARPA-H for health research.

University Research

University research is supported through a number of agencies, including DOD, DOE, and NIH, to help them achieve mission goals. However, NSF funds university research largely unrelated to the agency's mission goals. While the system is based on the conception of the linear model of research (first proposed by White House science advisor Vannevar Bush in the post-war period and based on the notion that funding for investigator-directed basic research will lead to valuable outcomes automatically), some argue that federal funding for university research should take a more explicit account of the needs of the commercial economy and promote tech transfer. However, in part because of cuts at the state government level and more recently federal funding cuts, university R&D levels relative to GDP in the United States lag behind many nations. In fact, the United States ranks 28th out of a representative group of 39 industrialized nations in government funding for university research as a share of GDP, with 12 governments among the higher-ranked nations investing more than double the U.S. investment. Between 2011 and 2017, U.S. government funding for university research as a share of GDP fell by nearly a quarter—0.06 percentage points. On average, nations decreased 0.03 percent of GDP during that time.[61]

Technology Transfer Systems

Prior to the 1980s, technology transfer (from universities or federal labs to the commercial marketplace) was largely an afterthought, at least as far as federal policy was concerned. To be sure, some institutions, such as MIT and Stanford, have long played an important role in working with industry and supporting new business spin-offs. However such efforts were largely due to unique institutional factors and were not widely adopted by publicly supported research institutions. However, since the 1980s, a range of policies have been put in place to help better commercialize research. Congress passed the Stevenson-Wydler Technology Innovation Act in 1980, which stated that "technology and industrial innovation are central to the economic, environmental, and social well-being of citizens of the United States." The Act made a number of changes to better enable the transfer of technology from federal laboratories to commercial use. Likewise, the Bayh Dole Act changed the IP rules governing federally funded research at universities, allowing universities to retain IP rights, and giving them more incentive to commercialize research. Congress also passed the Federal Technology Transfer Act of 1986, the National Defense Authorization Act for FY1991, the Technology Transfer Improvements and Advancement Act, the Technology Transfer Commercialization Act, and the Omnibus Trade and Competitiveness Act in 1988 (which, among other things, created the Technology Administration in DOC, reorganized the National Bureau of Standards into NIST, and created a number of programs to help industry with innovation, including the Malcolm Baldrige Quality Award, the Advanced Technology Program, and the Boehlert-Rockefeller State Technology Extension Program). In addition, some agencies, such as NSF and NIH, have begun pilot programs such as I-Corps, to better link their funded research to commercialization outcomes.[62] Overall, while policies have been put in place to help spur commercialization, the only federal agency explicitly focused on commercial innovation is NIST.

For over a century, the U.S. Department of Agriculture has supported a system to help farmers and ranchers adopt the best production technologies. These include a system of agricultural land grant colleges, agricultural research stations, and a county-wide system of agricultural extension agents. In 1989, Congress created a similar, albeit much smaller, system to help small and medium-sized manufacturers adopt new technologies.

The program, the Manufacturing Extension Partnership (MEP), is run by NIST and administrated by over 60 regional centers. There are also other much smaller systems in place run by other agencies to help firms with issues such as energy efficiency and worker safety. However, relative to many other nations (e.g., Germany and Japan), U.S. support for these systems is quite modest.[63]

However, the federal government has supported some industry-specific efforts related to industry R&D. For example, SEMATECH and the StarNet program have supported advanced R&D in the semiconductor industry—the latter program with industry and government funds a number of university research centers focused on advanced semiconductor research.[64] These efforts will be expanded with the $13 billion in funding from the CHIPS Act for semiconductor research.

Support for Research in Business

In the United States, most commercial activities are conducted by private, for-profit firms. The United States generally does not support R&D directly in firms, unless that R&D is related to achieving a core mission, especially defense. In part, this is because of an aversion toward anything that might smack of heavy-handed industrial policy. But it also reflects a belief that firms are often better positioned to identify the technology areas of most commercial promise. However, the federal government does support an array of policies to help firm-level innovation. For example, in 1981, Congress established a tax credit for business R&D expenditures. In addition, the SBIR program (which requires federal agencies to allocate a small share of their R&D budgets to small business research projects related to agency mission goals) was established in 1984. However, the SBIR program could be reformed to make it a more effective tool for innovation.[65] Likewise, Congress passed the Cooperative Research and Development Act in 1984 which allows companies to gain an antitrust exemption for participating in pre-competitive R&D consortia.

All of these measures are largely technology and firm-agnostic, supporting innovation itself (e.g., the R&D credit). However, the federal government has supported some industry-specific efforts related to industry R&D. For example, SEMATECH and the StarNet program have supported advanced R&D in the semiconductor industry—the latter program with industry and government funds a number of university research centers focused on advanced semiconductor research.[66]

The Obama administration established a network of Manufacturing USA Institutes, modeled in part on efforts like those of the German *Fraunhofer* centers.[67] The first center established was a DOD center for additive manufacturing (named "America Makes") that brings together firms, universities, and several government agencies in a unique public-private partnership. A total of 15 have been established, with much of the government funding coming from DOD and DOE.[68] However, the funding levels are relatively limited, especially when compared with what other nations are committing. For example, on a per-GDP basis, Korea invests 89 times more than the United States in industrially oriented research, with Germany 43 times more, and Japan 15 times more.[69] And China purportedly has proposed a system of 45 such centers funded on a significantly larger scale than the United States.

3.3.2. Decentralized Science and the Problem of Cross-Agency R&D Coordination

U.S. postwar decisions have played a significant role in determining the subsequent framework and processes for U.S. science and technology. The National Science Foundation was not created until 1950 and did not receive significant funding until the "Sputnik" crisis of 1957; in the interim, a plethora of R&D organizations either expanded or was created, generally attached to larger mission-based agencies. This meant that the U.S. would have decentralized science agencies independent of each other, where coordination across agencies would be difficult and complex. While an Office of Science and Technology Policy was created in 1976 within the White House for such coordination, as well as to provide the President with science advice, this office does not control science budgets so has had limited coordination authority.

3.3.3. Systems of Knowledge Flows

Innovation Clusters

The concept of innovation clusters has been long understood by regional planners (harkening back to “Marshallian” manufacturing learning districts in the early 1900s). However, it was not until Harvard Business School professor Michael Porter popularized the notion of clusters in the 1990s that many governments in the United States began to focus more explicitly on spurring innovation clusters. Of course, the emergence of a few high-profile clusters such as Silicon Valley and North Carolina’s Research Triangle Park (RTP) lent credibility to the notion that innovation clusters can power innovation and growth. Despite this, the federal government has not played an explicit role in the development of innovation clusters. To be sure, funding from the federal government (especially DOD in Silicon Valley and Boston’s Route 128 and NIH in RTP) has played a key role in the development of some U.S. innovation clusters. But explicit innovation-cluster policies have been the province of states and sub-state regions, in part because these units of governments are “closer to the ground” and have a better sense of which clusters are important. Toward that end, many U.S. states have innovation-cluster programs and policies.[70] There is also a growing concern that technology has become too concentrated in just a few leading hubs and that the federal government should step in to help more regions thrive.[71] The recent CHIPS and Science Act did contain funding to support “regional innovation hubs” but the funding is quite limited, and many of the selected hubs appear to have been chosen for climate policy goals, rather than national competitiveness goals.[72]

Industry Collaboration Systems (With Academia and Research Institutes)

Compared with many nations, the United States has a highly developed and successful industry-research institute collaboration system. Universities such as MIT, Cal Tech, and Stanford are models for the rest of the world, and indeed, other universities in America, look to for inspiration. There is no single reason for U.S. success at university-industry collaboration; rather, a number of factors play a role. One factor is culture. A long tradition of John Dewey-like pragmatism has dominated U.S. universities, leading them to view collaboration with industry not as something that sullies the purity of basic research, but rather as something that is useful and can advance knowledge. In addition, the U.S. system, with a diversity of kinds of universities and ownership (with a large number of world-class private universities), has created a more competitive environment wherein universities innovate and compete to work with industry. On top of this, U.S. universities are much less hierarchical than universities in many other nations, where faculty must wait until they become full professors to work with industry or start new companies. Finally, in many states, public colleges and universities are encouraged and supported by state and local governments in their efforts to work more closely with industry.

Despite this overall positive record, it's important to note that there is still great diversity in commercialization performance. For every MIT or Stanford, there are 10 universities wherein commercialization is more haphazard and less effective.[73] NSF's Engineering Research Center (ERC) and Industry/University Cooperative Research Center (I/UCRC) programs have also played a role in facilitating university-industry collaborative research into complex engineered systems. However, both programs receive limited funding, and the ERC program has limited industry engagement.

Acquiring Foreign Technology and Exporting U.S. Technology

In part, because the U.S. economy is so large and is generally at the leading edge of technology development, there has been little explicit policy directed at acquiring foreign technology. The general policy approach has been to welcome inward foreign direct investment (FDI) because of the technology transfer that it brings. To the extent that government supports inward FDI attraction, that support has been at the state and local levels. For example, in the 1980s and 1990s, states aggressively courted Japanese automobile company investment in part for the jobs they provided, but also because of the technology transfer that occurred as U.S. auto firms were more easily able to learn the Japanese system of auto production. However, more recently, the Obama administration has established Select USA, a small initiative in DOC designed to work with the states to help attract foreign investment. However, according to DOC data, less than 1 percent of all foreign investment to the United States is in the form of greenfield investment in new manufacturing facilities.

In addition, the United States monitors foreign acquisitions of U.S. companies through the Committee on Foreign Investment in the United States (CFIUS). CFIUS is an inter-agency committee authorized to review transactions that could result in control of a U.S. business by a foreign entity ("covered transactions"), in order to determine the effect of such transactions on the national security of the United States. Most foreign acquisitions of U.S. companies do not even trigger a CFIUS review, and few transactions are rejected. In part, this reflects a belief that foreign acquisitions of U.S. firms can in many cases provide needed injections of capital, know-how, and market access that can help the U.S. establishment become more competitive. However, because of the increasing worry about predatory acquisitions by China, Congress passed the Foreign Investment Risk Review Modernization Act of 2018, which gave more resources to the administration and more tools to limit foreign investment in the United States, especially by U.S. adversaries. Since then, Chinese investment has fallen significantly.

With regard to exporting technology, there are few limits on exporting U.S. commercial technologies to other nations, unless those technologies have potential benefits for current or potential military adversaries. As a result, DOC's Bureau of Industry and Security oversees the transfer of certain sensitive U.S. technologies to some foreign nations. But again, the number of technologies covered is relatively small. Moreover, in the past decade, there has been increasing pressure from industry and others to reduce the restrictions in order to boost U.S. innovation competitiveness. At the same time, the growing concern that China is acquiring too much U.S. technology, coupled with the growing interest of the Trump administration to hamstring some Chinese technology firms, especially those with ties to the Chinese military, has made export controls a more widely used tool. In addition, the Bureau of Industry and Security (BIS) was charged by Congress with coming up with a list of Emerging and Foundational Technologies that should be limited in terms of exports.[74]

Technology Diffusion and Adoption

In the United States, there are several policies and programs related to diffusion and adoption. For over a century, the U.S. Department of Agriculture has supported a system to help farmers and ranchers adopt the best production technologies. These include a system of agricultural land grant colleges, agricultural research stations, and a county-wide system of agricultural extension agents. In 1989, Congress created a similar, albeit much smaller, system to help small and medium-sized manufacturers adopt new technologies. The program, the Manufacturing Extension Partnership (MEP), is run by NIST and administrated by over 60 regional centers. There are also other much smaller systems in place run by other agencies to help firms with issues such as energy efficiency and worker safety. However, relative to many other nations (e.g., Germany and Japan), U.S. support for these systems is quite modest.[75]

3.3.4. Human Capital System

Education/Training (K-12)

The United States' K-12 education system is largely operated at the state and local level, with thousands of local school districts. Unlike many other nations, the United States has not established federal control of the K-12 system. However, the development by the states (and supported by the federal government) of the "Common Core" standard is a move to bring more interstate uniformity.

Compared with many other nations, the performance of U.S. K-12 students on internationally comparable standardized tests such as PISA and TIMMS is generally lacking. Some argue that the poor performance reflects a lack of national curriculum standards, while others argue that it is more structural in nature (teachers' unions resistant to change, or too little school choice). However, it is generally not a result of lack of funding, as U.S. funding per pupil is above the OECD average. In part, this poor performance is because of the higher share of students in the United States from socioeconomically disadvantaged families.

One feature of the U.S. K-12 system that is different from that of many other nations is the increased diversity of kinds of schools. Since the 1980s, the growth of "charter" schools (publicly funded, but privately operated) has been significant, with many of the charters focusing on unique pedagogical approaches. In addition, the United States has a higher share of students in private (religious and non-denominational) schools than most other nations. Finally, despite the relatively mediocre test scores, the U.S. K-12 education system does appear to do a better job than many other national education systems in encouraging independence and creative thinking among students. In many schools, students are encouraged to not just engage in rote learning (e.g., "drill and kill") but in more creative activities and independent thinking. This appears to play a supportive role in U.S. innovation and entrepreneurship. However, with the rise of the standards movement, such activities may have diminished. In addition, the gradual movement to add more required courses to the U.S. high school curriculum has meant students have less choice of classes that may interest them. These changes may be why only around 40 percent of high school students report being satisfied with their school.[76]

Higher Education

The American higher education system is diverse and distributed in nature. As previously described, states manage public universities and colleges while private universities are funded through tuition and charitable donations. For private schools, some students can afford high tuition while others receive financial aid from the universities. Public state schools are subsidized, but with the fiscal problems of state governments, tuition rates have increased significantly as public funding has been cut. This is one reason the United States has fallen behind many other nations in higher education enrollment rates.

In addition, there is little national or state effort to guide students in their choice of what to study. On the one hand, this helps students choose majors in response to market forces; but it also means there is an undersupply of graduates in STEM.

There is also increasing evidence of low levels of learning in U.S. colleges and universities. Sociologists Richard Arum and Josipa Roksa administered the Collegiate Learning Assessment to several thousand college students at over two dozen institutions when they began college and again at the end of both their sophomore and senior years. They found that, if the test were scaled on a 0-to-100 range, 45 percent of the students would not have demonstrated gains of even one point over the first two years, and 36 percent would not have shown such gains over four years.[77]

Because of COVID and the rise of online learning, it is possible the U.S. system will move more to massive open online courses (MOOCs) with a significant increase in higher education productivity as more students take more classes online. In addition, President Trump's executive order to no longer require the U.S. Office of Personnel Management

OPM to include college degree requirements in job announcements (relying instead on actual capabilities), could help disrupt the higher education system.[78]

Finally, an increasingly large share of students participating in master's or Ph.D. programs in STEM fields at U.S. universities are foreign-born, reflecting both the global quality of U.S. research universities and the difficulty in developing a pipeline of U.S. students studying toward STEM degrees.[79] However, many of these students are from China, and there is increasing concern that some of them may be using that access to steal IP for China.

Skills/Technical Training

In the United States, skills training is largely seen as a private-sector responsibility. As such, there is no national system for employer-based skills training. In the old economy, employers played a stronger role in skills training, with some industries and firms taking the lead with the establishment of training institutes and industry-wide apprenticeship programs. But over the past three decades, most of these efforts have ended as firms have seen such investments in "public goods" as something they can no longer afford. As such, overall private-sector investment in skills training has declined by about one-third as a share of GDP in the last decade.[80]

To the extent that there is a federal role (through the Department of Labor), it is focused largely on helping disadvantaged individuals obtain skills. However, the National Skill Standards Act of 1994 created a National Skill Standards Board (NSSB) responsible for supporting voluntary partnerships in each economic sector that would establish industry-defined national standards leading to industry-recognized, nationally portable certifications. The vision was that each industry would define and validate national standards for the skills it was seeking, and credential individuals against those skills. One key reason for doing this was so companies would have a better way to assess the skills of prospective and current workers, and workers would have a better way to identify and gain the skills they needed to be successful. But the federal government failed to provide matching funding to establish this standards-based system. Moreover, in the 2000s, the national sectoral approach was abandoned in favor of a regional approach.

However, a number of states have established skills training programs. For example, Wisconsin and Georgia have strong youth apprenticeship programs. Some states and local school districts have established career academies within high schools. Several have established regional skills alliances—industry-led partnerships that address workforce needs in a specific region and industry sector. For example, Michigan has provided competitively awarded start-up grants and technical assistance to 25 industry-led regional skills alliances. Pennsylvania's $15 million Industry Partnerships program brings together employers and workers (or worker representatives, when appropriate) in the same industry cluster to address overlapping human capital needs. Other states have established tax credits for company investments in workforce development. California has a deduction for training expenses if a company has spent a certain share of sales on training. Firms in Rhode Island can deduct up to 50 percent of training costs on their corporate income taxes.

Moreover, a core component of the U.S. skills training system is the system of community colleges the nation enjoys. The community college system is a critical partner in training the current and future workforce. Community colleges play a vital role in training job seekers with the skills to obtain a good job, while simultaneously helping employers obtain the workers they need to stay competitive. For example, more than half (55 percent) of the 1,600 community colleges in the United States offer specialized training in manufacturing skills. In addition, there has long been interest in expanding apprenticeship education, most recently by the Trump administration. However, funding for such programs has been limited.

Immigration Policy

More than many nations, the United States has relied on high-skill immigration to support its innovation system. This has paid off to date. At least eight studies have examined the role of immigrants in launching new companies in the United States, and all conclude that immigrants are key actors in this process, creating from 15 to 26 percent of new companies in the U.S. high-tech sector over the past two decades.[81] Another study found that more than one-third (35.5 percent) of the most important U.S. innovators were born outside the United States, even though this population makes up just 13.5 percent of all U.S. residents.[82] Some U.S. states have seen even greater beneficiaries: Nearly 40 percent of the engineering and technology firms founded in California and New Jersey between 1995 and 2005 were founded by foreign-born immigrants.[83]

Overall, in comparison with many other nations, including Canada, the U.S. system is not focused on high-skill immigration. However, until the Trump administration, its overall liberal immigration policy meant that many STEM workers could immigrate to the United States. The United States also has a temporary employer-sponsored work visa system, the H1b visa program. However, the Trump administration has worked to limit immigration overall, and H1b workers in particular.

4. U.S. Innovation System Strengths and Challenges

There is no national, coordinated innovation policy system in the United States. While some nations have developed national innovation strategies (e.g., Germany, Sweden, and Finland), the United States generally has not. This reflects in part a belief that innovation is best left to the market and that the role of government, to the extent there is one, is to support "factor inputs," such as knowledge creation and education.

However, that may be changing in response to the economic, technological and military challenge from China. Indeed, national innovation systems are evolutionary, not static. Moreover, the innovation environment itself evolves, which can change the relative strength of an NIS or individual components, as they either reflect a better or worse fit with the new environment. As such, a nation's overall innovation system, as well as individual components, can improve or degrade. For the U.S. innovation system, it appears that the direction of change has been relatively worsening, especially when compared with some other national systems whose governments are putting in place a suite of policies designed to win in the global race for innovation advantage.[84]

Clearly the United States has important strengths in a number of areas. These include: managerial talent; venture capital financing system in the world; strong risk-taking and entrepreneurship culture; a reasonably good business climate, including the ability of employers to lay off workers; a large domestic market; world-leading technology firms, especially in the IT sector; world-leading software capabilities; strong IT adoption by business; reasonably good system to technology transfer from universities to the private sector; a balanced intellectual property system; some of the world's top research universities; and attractive location for high-skill immigrants; relative strengths in services and business model innovation.

The U.S. innovation system finds itself facing an array of challenges. These include: companies pressured for short-term investment results, especially outside of leading IT companies; weak capabilities to scale up innovations domestically, limited government support for R&D, especially commercial R&D; a tax code with weak incentives for investing in R&D and new capital equipment; Relatively low levels of domestic STEM talent production, lack of a lack of national S&T strategy; relative lack of interest among elected officials in innovation; spasmatic tech policy efforts with occasional short-term flourishes followed by periods of disinterest, lack of governmental efforts to effectively lead and coordinate innovation policy, especially across the whole of government; a view of trade policy and globalization that makes effective responses to mercantilist nations practices difficult; an R&D system that is mission-oriented with little attention paid to the mission of boosting international commercial innovation competitiveness, lack of innovation analytical capabilities within government and lack of interest in benchmarking the United States against peer competitors.

At the same time, the United States has a number of factors that while used to be strengths are going into the wrong direction and trending toward weakness. These include: an increasingly negative attitude toward technological innovation characterized by fear; an increasing adoption of a precautionary principle orientation to regulation of new technologies; a growing anti-corporate animus where large companies are blamed for much of society's problems, a problematic portion of the workforce with inadequate skills and attitudes, at both the blue collar and white collar levels; a short time Horizon and an unwillingness of the public to support investing in the future; a split in economic doctrines guiding policy between free-market laisse faire and big-government progressivism;[85] a university system that has lost focus on holding students to high academic standards; growing limits on STEM immigration; stagnant or declining government S&T funding.

But there are a number of other factors wherein the U.S. position is clearly trending down, especially in relation to other national innovation systems. These include funding support for universities and federal labs and other innovation inputs as federal policymakers continue their unwillingness to prioritize investment in the federal budget process. Indeed, this is a component of a broader factor of the unwillingness of American society to invest in the future and collective goods. There is little evidence that American voters are willing to sacrifice additional current income and consumption for investments in the future. At the same time, this pressure for immediate gratification is reflected in the investment decisions by publicly traded corporations. Again, there is little evidence that the pressures from equities markets for immediate returns will abate any time soon. Even more, there is a disturbing turn to "neo-Luddism" in America as so-called "public interest" groups, the media, pundits, and other elites adopt an anti-innovation attitude, whether it relates to genetically modified organisms, the use of data and AI, or automation. Given the complicity of the media in this process, which increasingly adopts the view that "fear grabs eyeballs," the likelihood is that neo-Luddite, anti-progress forces will strengthen, particularly among liberals, making the overall innovation environment more problematic.[86]

Thus, the challenge for the United States going forward is whether it can make the needed changes to its innovation system to meet the new competition. Our economic future and national security will depend on the answer.

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Chapter 4

Korea

JEONG Hyeok, KWON Seok Beom

1. Korean Economic Growth and Innovation Performance

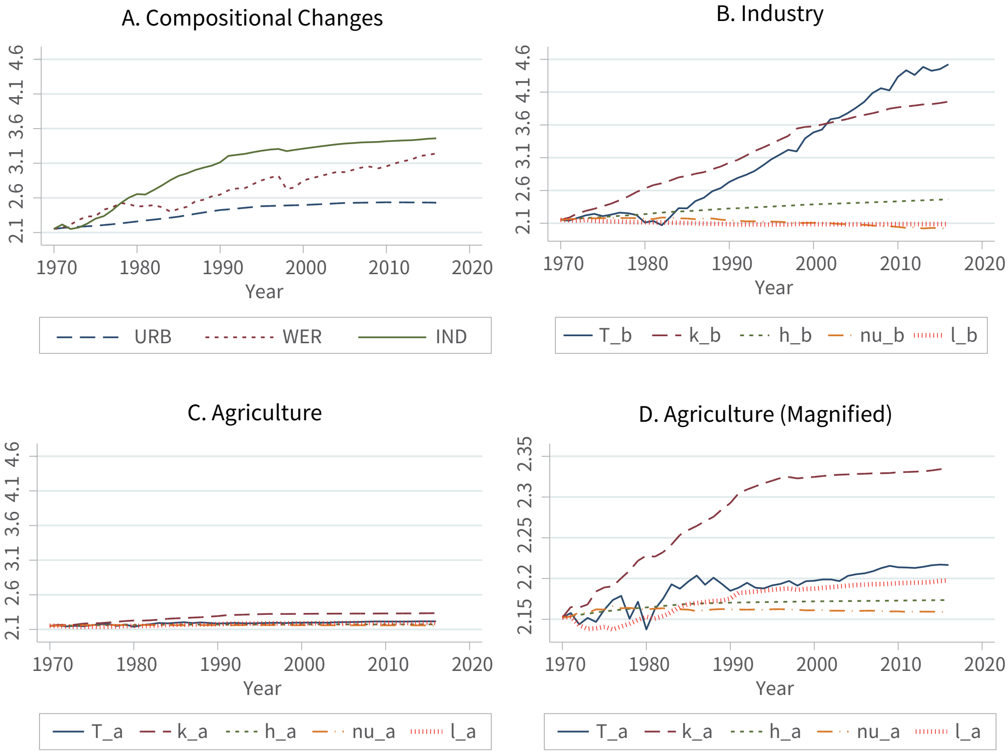
1.1. Korea's Economic Growth and Role of Productivity

Extreme poverty still prevailed in Korea according to any socioeconomic and political measures for a while even after Korea's liberation from Japanese colonial rule and the armistice of the Korean War. The shackles of such absolute devastation started to be broken only after 1960 and the real GDP per capita grew by 6% per year for the following 60 years in the Republic of Korea ("Korea" for short hereafter). Jeong (2023) calls this growth performance of the Korean economy as "6p-6d" performance (annual average growth rate of 6 percent for 6 decades) and analyzes the secrets behind it. Nowadays most people all around the world, not just a limited group of policymakers, have begun to recognize and appreciate such a miraculous transformation from one of the least developed countries to one of the major global trading and investing economies. Their main point of impression is about how such rapid transformation was possible for such a short period of time, considering the long and gradual development paths of the so-called "Western economies." That is, they pay attention to the speed of Korean economic growth.

Recent studies by Jeong (2018, 2020) show that speed indeed was an important feature of Korean economic growth, ranked as *number one* in terms of the annual average growth rate of real GDP per capita during the six-decade period of 1960-2019. Most successful take-off countries escaping from poverty and entering into the growth regime show rapid growth. According to Hausman, Prichette, and Rodrik (2005), this kind of "growth acceleration" episodes are frequent and their growth rates are often higher than 6%. Furthermore, in fact, such growth episodes have been observed among Latin American and African countries since the 1960s. However, such successful take-off countries could maintain their rapid growth mostly less than ten years. Some of the current emerging economies did it for 15 to twenty years. China did it for 30 years. All of them, perhaps with the possible exception of China, have faced rapid stagnation as well and still remain as middle-income countries. This is the famous phenomenon of the "middle-income trap," and this law has applied to almost all developing countries. Korea was the only exception, switching from a least-developed country to a middle-income country and then to a high-income country after sixty years of incessant growth. Korea had stayed in the middle-income group for less than ten years since its take-off. This exceptional development experience in Korea happened in the 1980s.

Jeong (2018, 2020) shows that such an escape from the middle-income trap and the following sustained growth were possible because of the transformation of the main engine of growth from input-driven to productivity-driven one in the 1980s. This second-round transformation of the Korean economy is the fundamental secret behind Korea's sustained economic growth for sixty years. The Korean annual average rate of within-sector TFP growth was -0.26% in the 1970s, and the major engine of growth in the 1970s was capital accumulation (2.35%) and compositional shift from agriculture to manufacturing and service sectors (2.12%). However, the annual average rate of within-sector TFP growth in Korea turned to 2.82% in the 1980s, 2.54% in the 1990s, and 2.27% in the 2000s (Jeong, 2020). Figure 4.1 displays the decomposed contributions of various factors behind the Korean economic growth by creating counterfactual income paths isolating the real GDP per capita growth from each single factor. This clarifies that the biggest contributing factor to Korean economic growth since 1970 is productivity growth, particularly within the industry sector.

Figure 4.1. Decomposition of Korean Economic Growth and the Role of Productivity



Source: Figure 14 in Jeong (2020)

Legend Note: URB (Urbanization), WER (Within-sector Employment Rate), IND (Industrialization), T_i (TFP of sector i), k_i (Capital per worker of sector i), h_i (Human capital per worker of sector i), nu_i (Work hours per worker of sector i), l_i (Land per worker of sector i), i = a for agriculture, b for industry

Many things happened in Korea in the 1980s. Some are crucially related to the characteristics and the directions of the Korean innovation system build-up. The essence of those transformations can be described by democratization, decentralization, and private-sector-led innovation facilitated by government.

Korea went through a series of serious democratization movements in the 1980s. Such political democratization was also accompanied with economic democratization. Resource allocation mechanisms were decentralized in many significant ways. There were a series of trade liberalizations in the 1980s and 1990s. Korea is considered one of the most active export-promotion economies. This is true, but only half true. Korea was active in import as well as export, and import in the 1980s and 1990s was an important channel of technology transfer. Of course, to overcome the pressure from global competition from participating in the global market via export promotion, domestic technology development was also intense. In fact, the 1980s was when the ship-building, automobile, and semiconductor industries started to engage in global markets. For example, it was in 1983 when Samsung succeeded in developing the 64Kb DRAM, which was the third earliest in the world. This was a watershed event for the Korean semiconductor industry flaring its future prevalence in the global semiconductor market.

Furthermore, key price variables such as inflation, interest rate, and foreign exchange rate were deregulated, and the Korean macroeconomy was stabilized so that the macroeconomic risks for the investment were reduced. These macroeconomic environments favored the innovations. The innovation governance was also switched to supporting private-sector-led innovation investments. The main goals of the science and technology policies in the 1960s and 1970s were to back up the planned economic growth and industrial development. However, starting from the 1980s, the main goals of the science and technology policies turned to promote innovations per se, and R&D investment drastically expanded. These fundamental socio-economic transformations were behind Korea's switch from an input-driven to a productivity-driven growth mechanism in the 1980s, which was sustained for the following thirty years.

During the last decade since 2012, the Korean annual growth rate of real GDP per capita entered into the range of 2-3%. Slow-down of growth rate is a natural phenomenon as an economy gets matured because the rate of return to capital investment becomes smaller as the accumulated stock of capital becomes large enough. However, the real problem in the Korean economy is that the TFP growth, which has been the major source of Korean growth, is also decreasing. The TFP growth near the steady state indicates the potential magnitude of the long-run growth. Korean annual TFP growth rate for the last decade is in the 0.5-0.6% range. Whether this lowered TFP growth will be maintained or bounced back in the near future is a critical challenge for the Korean economy. Promotion of productivity hinges on innovation activities, and hence on the national innovation system. From this perspective, reviewing and also renewing the Korean national innovation system is of the utmost importance for beaconing the pathway to Korea's future prosperity.

1.2. Innovation Capacity and Performance Measures

1.2.1. Analysis of Global Innovation Index

WIPO has compiled the cross-country data of the five categories of input variables (Institutions, Human capital and research, Infrastructure, Market sophistication, and Business sophistication) and two categories of output variables (Knowledge and technology outputs, and Creative outputs) in relation to the innovation process, and provides a composite index called "Global Innovation Index" (GII) to represent the country level innovation capacity for the 2011-2022 period. According to the three-year average score of GII during the most recent sample period of 2020-2022, Korea is ranked 6th scoring 57.7. The 2020-2023 three-year average score of GII ranges from 11.9 (Iraq) to 65.4 (Switzerland). Table 4.1 lists the top 20 countries reporting their scores and the changes in scores compared to those of the initial sample periods of 2011-2013. Among the top 20 countries, only six countries improved their scores by more than one point compared to the initial 2011-2013 three-year average score. They are the rank 3rd USA (+3), rank 6th Korea (+4.1), rank 9th Germany (+1.4), rank 11th France (+3.3), rank 12th China (+9), and rank 13th Japan (+2.2). The GIIs of the rest 14 countries among the top 20 declined. Except for Taiwan whose data are not collected by WIPO, all four countries of this Project turn out to be the improvers in innovation.

According to the GII score, the absolute level of Korea's innovation capacity has been increasing for the last decade and reached the world ranking at 6th as of the year 2022, only lower than Switzerland, Sweden, the USA, UK, and Netherlands, and higher than Finland, Singapore, Germany, Denmark, France, China, Japan, Hong Kong, and Israel. There are seven categories of innovation inputs and outputs that determine the overall GII. Observing Korea's relative positions of each sub-index, we can identify Korea's relative strengths and relative weaknesses across different dimensions of innovation. Table 4.2 shows Korean sub-index scores relative to the mean value for the underlying seven categories. By comparing Korea's score of GII relative to the mean (1.76) with Korea's score relative to the mean for each category of innovation dimension, we can tell that Korea's relative weakness lies at the areas of Institutions, Infrastructure, and Market sophistication areas, while relative strength lies at the areas of Human capital and research,

Table 4.1. **Global Innovation Index Comparison (2020-2022 Period Average)**

Rank	Economies	GII (2020-2022 Avg)	Change from 2011-2013 Avg
1	Switzerland	65.4	-0.8
2	Sweden	62.4	-0.4
3	**USA**	**61.2**	**3.0**
4	UK	59.8	0.3
5	Netherlands	58.5	-0.8
6	**Korea**	**57.7**	**4.1**
7	Finland	57.4	-2.2
8	Singapore	57.2	-3.6
9	**Germany**	**57.0**	**1.4**
10	Denmark	56.9	-1.5
11	**France**	**54.6**	**3.3**
12	**China**	**54.5**	**9.0**
13	**Japan**	**53.6**	**2.2**
14	Hong Kong	53.2	-5.7
15	Israel	52.4	-3.0
16	Canada	52.1	-4.9
17	Ireland	50.7	-6.2
18	Austria	50.4	-1.5
19	Iceland	50.2	-5.6
20	Luxembourg	49.9	-5.8

Source: Author's calculation using WIPO Global Innovation Index

Business sophistication, Knowledge and technology outputs, and Creative outputs. As a robustness check, we repeat a similar comparison by using the maximum as a normalizing value. Korean GII relative to the max value is 0.88. Using these relative metrics, Korea's relative weakness lies in the areas of Institutions, Market sophistication, and Knowledge and technology outputs, while its relative strength lies in Human capital and research (Korea is the frontier). Combining these observations, we may conclude that Korea's priority innovation dimensions are Institutions, and Market sophistication, while Korea should keep up the dimension of Human capital and research. Institutions category is about the political environment (political or security risks, quality of civil services), regulation environment (policy cohesion to promote private sector development, rule of law, and cost of redundancy dismissal), and business environment (ease of doing business). The market sophistication category is about access to credit, minority investor protection, trade, intensity of competition, and market scale. The human capital and research index is about the quantity and quality of education, higher education, and R&D activities.

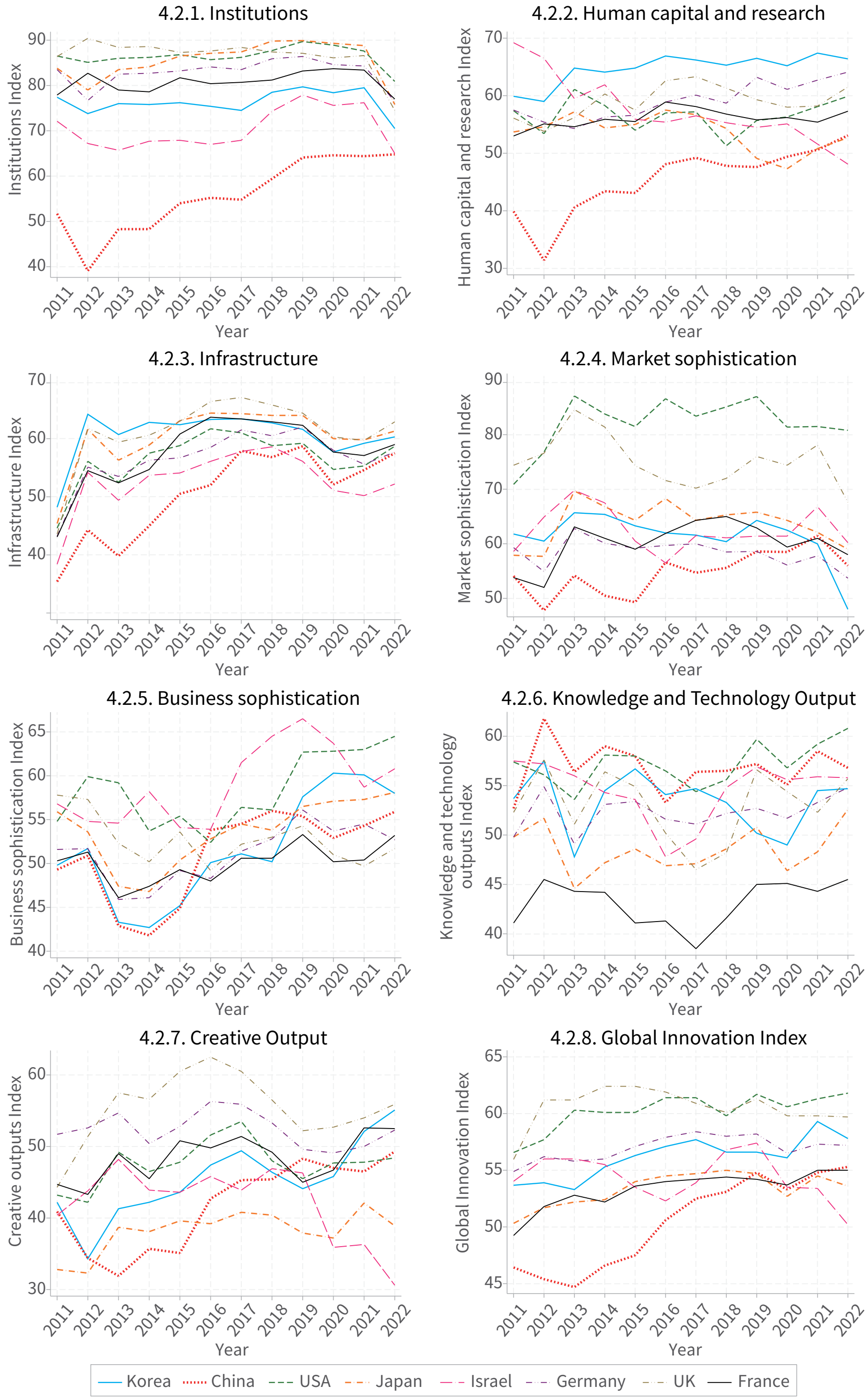
Figure 4.2 shows the Korean trends of the seven sub-indices and the overall GII index in comparison with those of major innovation countries such as the USA, Germany, France, Japan, China, and Israel. Korea's GII has been steadily rising since 2011. This increasing trend of Korean GII is due to the rise of the indices of Human capital and research, Business sophistication, and Creative output. Infrastructure Knowledge and technology output areas are stagnant. For the two relative weakness areas of Institutions and Market sophistication, the indices have been falling. This suggests that there exists an urgent need to improve the institutional and market environments.

Table 4.2. **Korea's Relative Position by Innovation Categories**

Innovation Categories	Korea	Max	Mean	Korea/Mean	Korea/ Max
Institutions	76.1	95.3	61.7	1.23	0.80
Human capital and research	66.3	66.3	32.0	2.07	1.00
Infrastructure	59.1	65.3	41.3	1.43	0.90
Market sophistication	56.8	81.2	42.7	1.33	0.70
Business sophistication	59.5	68.6	30.6	1.95	0.87
Knowledge and technology outputs	52.7	65.5	24.1	2.19	0.81
Creative outputs	51.0	59.8	23.9	2.13	0.85
GII	57.7	65.4	32.8	**1.76**	**0.88**

Source: Author's calculation using WIPO Global Innovation Index

Figure 4.2. Changes of Innovation Input Indices



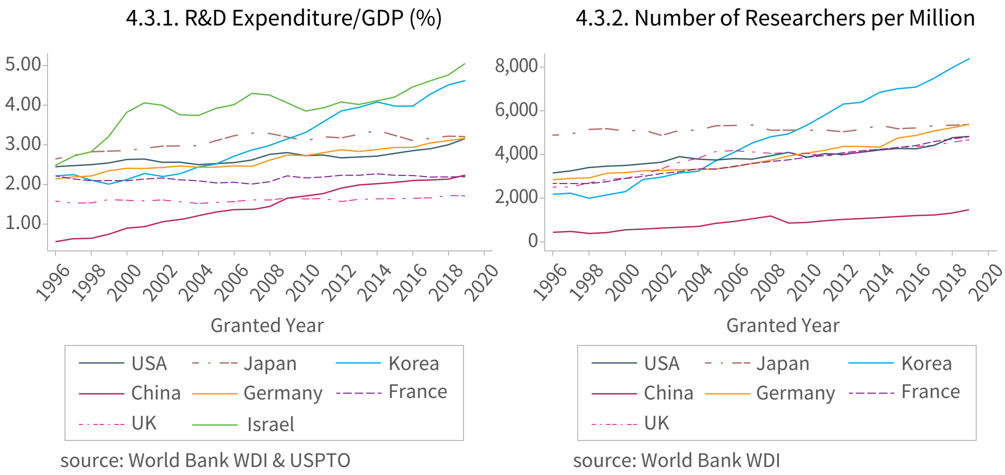
Source: Author's calculation using WIPO Global Innovation Index

1.2.2. R&D Activities

Figure 4.3 displays the R&D activities by monetary investment relative to GDP and also by the number of researchers per million people. Korea's R&D expenditure to GDP ratio has been increasing from 2.22% in 1996 to 4.63% in 2019, which is the second highest in the world, next to Israel (5.08%). There exists a discrete gap between Israel-Korea and the rest of the major innovating countries. The only country that shows significant growth in this measure is China. However, the 2019 value of Chinese R&D expenditure relative to GDP is similar to that of Korea's value in 1996.

Korea's number of researchers per million people increased from 2173 in 1996 to 8,408 in 2019 according to the World Development Indicators of the World Bank. The 2019 value of this variable is by far the highest and its speed of growth is also the fastest in the world in the WDI sample.[1] The 2019 values of the number of researchers per million people are 5,396 for Germany, 5,375 for Japan, 4,821 for the USA, and 1,471 for China.

Figure 4.3. R&D Activities

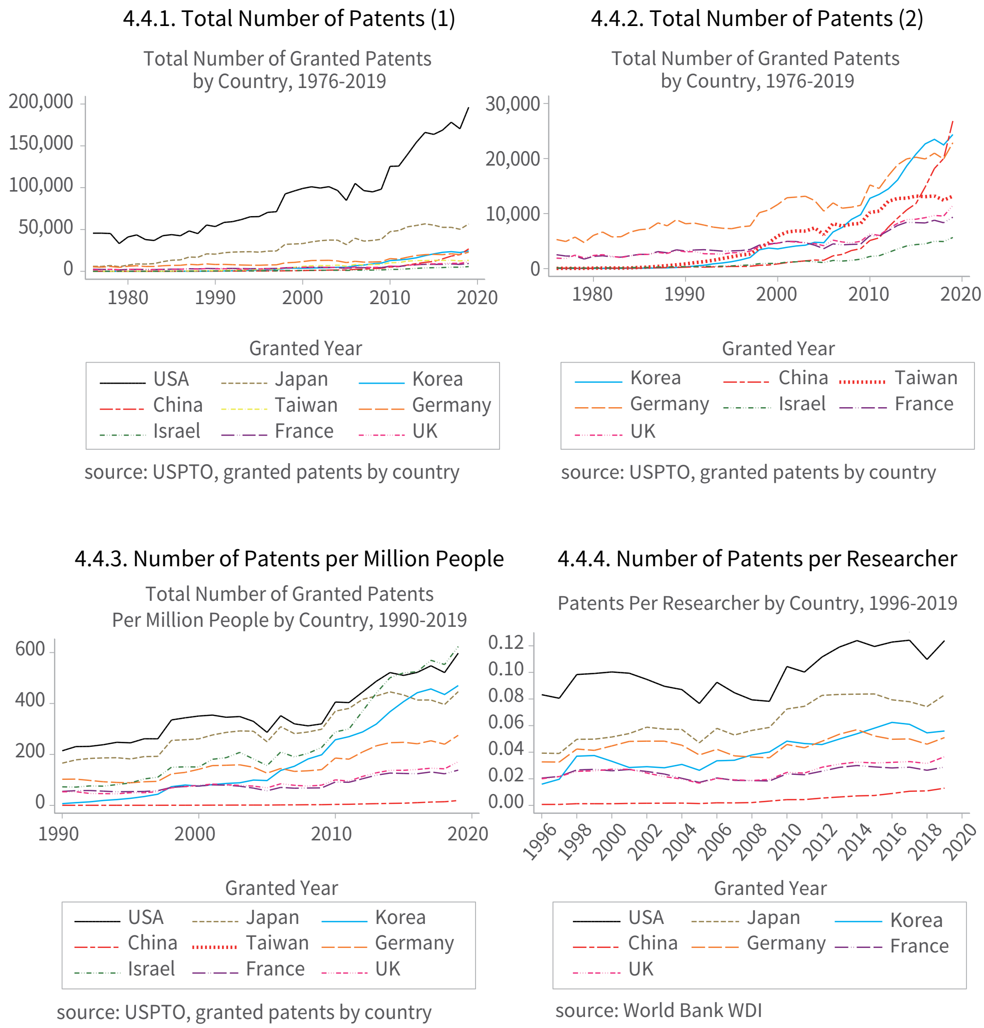


1. Israel's number of researchers per million people is not reported in WDI.

1.2.3. Patents Granted

Figure 4.4 displays the total number of patents granted, the number of patents per million people, and the number of patents per researcher. In terms of the total number of patents, the USA is by far the largest (196,108), followed by Japan (56,520). Korea's total number of patents increased from 1,576 in 1996 to 24,342 in 2019 at an annual average growth rate of 12.6%. Korea's 2019 total number of patents is similar to China (26,801) and Germany (22,859), and larger than Taiwan (13,160), UK (11,463), France (9,338), and Israel (5,645).

Figure 4.4. Patents Granted



When it is normalized by population size, the picture changes. Korea's number of patents per million people in 2019 is 470, which is the third highest, followed by Israel (623), and the USA (597), and is higher than Japan (446). Figure 4.4.4 shows the number of patents per researcher in order to evaluate each researcher's average productivity in generating patents. According to this measure, Korea is ranked third (0.056) in the world in 2019, next to the USA (0.124) and Japan (0.083), and higher than Germany (0.051), UK (0.037), France (0.029), and China (0.013).

1.3. Korea's Industrial Comparative Advantages: Hamilton Index Analysis

Hamilton index provides us with a method of analyzing cross-country comparative advantages of domestic production for the selected ten advanced industrial sectors as well as their overall concentration and strength in the global market. The ten sectors are Computers and Electronics, Electrical Equipment, Machinery and Equipment, Chemicals, Motor Vehicles, Other Transportation, Basic Metals, Fabricated Metals, IT and Information Services, and Pharmaceuticals. Figure 4.5 compares the production shares of these ten sectors of major industrial power countries for the two periods of 1995-2007 and 2008-2020. The world average in 2020 is 11.4%. The countries the shares of which exceed the world average in 2020 are Taiwan (24.4%), Korea (22.9%), China (18.5%), Germany (17.6%), Japan (15.4%), and Israel (13.4%). The shares of the US (9.9%), France (8.3%), and the UK (8.1%) are below the world average. This figure clarifies that Korea together with Taiwan has an outstanding concentration and strength of the Hamilton index industries. There exists a discrete gap between these two countries and the rest for this share. Furthermore, Korea is one of the three countries where the overall share of the ten sectors has substantially increased between 1995-2007 and 2008-2020 periods. The other two are Taiwan and Germany.

Figure 4.6 shows the trends of the shares of the ten sectors for the 1995-2020 period. The sectors with increasing trend of domestic production shares during the entire 1995-2020 period are Computers and Electronics, Electrical Equipment, Machinery and Equipment, and IT and Information Services. The sectors with increasing trend of domestic production shares for the recent 2008-2020 period are Pharmaceuticals. The declining sectors for the recent 2008-2020 period are Basic Metals, Fabricated Metals, Motor Vehicles, Other Transportation, and Chemicals.

Figure 4.5. Production Shares of the Ten Hamilton Index Industries of Major Industrial Powers

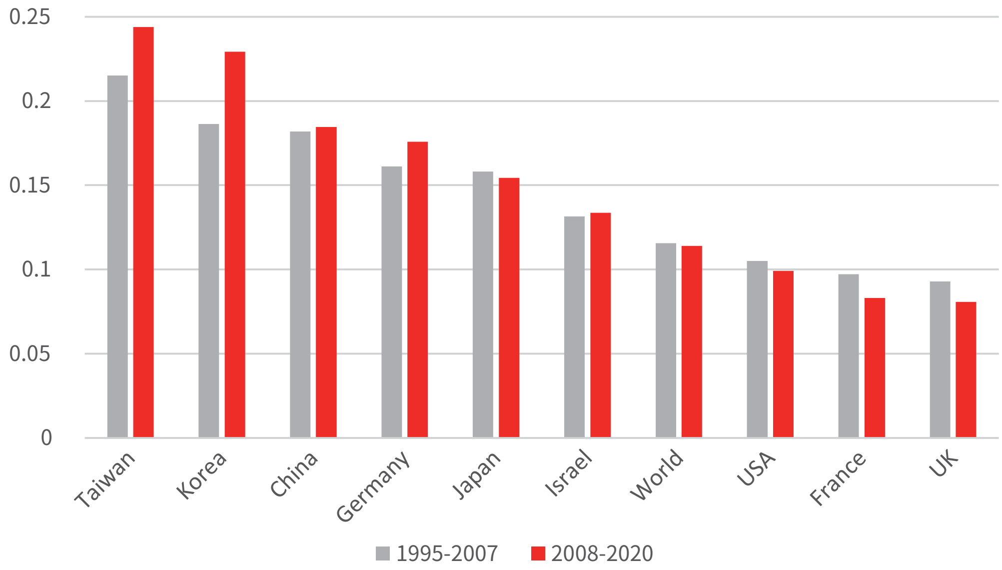
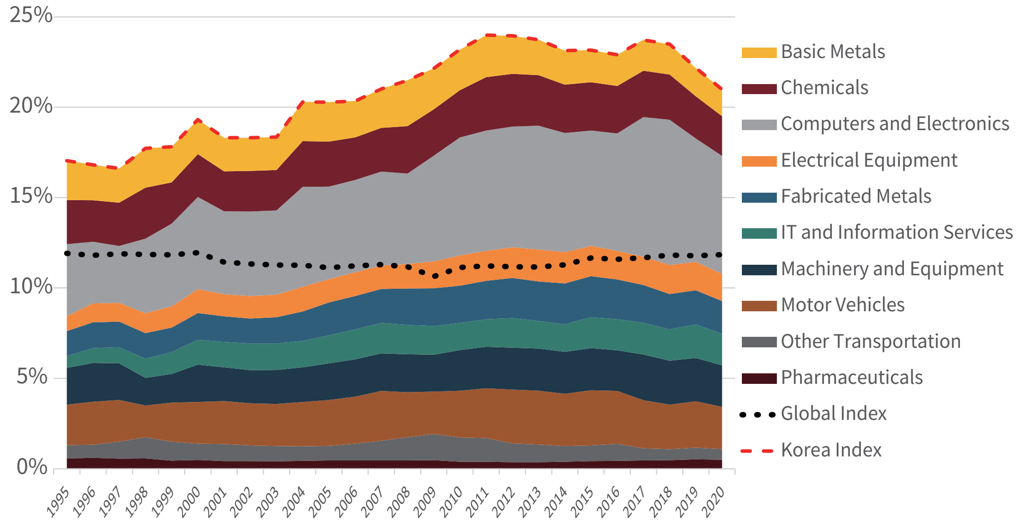


Figure 4.6. Korean Shares of Hamilton Index Industries



The domestic production comparative advantage of each sector can be measured by the LQ measure, defined by the ratio of the national GDP share of a given industry to the global GDP share of the same industry. Figure 4.7 displays the 2020 LQ's of the ten industries and its composite index. This illustrates that Korea has comparative advantages of industrial production for 8 out of 10 industries with exceptionally high LQ for Computers and Electronics (4.23) and Electrical Equipment (2.12). The two industries with weak LQ's are IT and Information Services (0.78) and Pharmaceuticals (0.61). Figure 4.8 displays the time trends of the LQ's of the ten industries, showing that the comparative advantages of the two exceptionally high LQ industries have been strengthening throughout the 1995-2020 period. The LQ's of the two weak industries have been further declining.

Figure 4.9 illustrates the changes of LQ's during the 2008-2020 period referencing the 2020 LQ values. The size of the bubble in Figure 4.9 indicates the 2020 GDP share of each sector. This figure shows similar reinforcing patterns of strengthening and weakening comparative advantages of domestic production. There exists a positive correlation between these two variables. The three sectors with high and increasing LQ are Computers and Electronics, Electrical Equipment, and Machinery and Equipment. The two sectors with low and declining LQ are IT and Information Services and Pharmaceuticals. It is interesting to notice that the GDP share of the weak IT and Information Services rose from 0.66% in 1995 to 1.68% in 2007, and then to 1.75% in 2020. The GDP share of Pharmaceuticals fell from 0.57% in 1995 to 0.46% in 2007 and increased back up to 0.50% in 2020. Korea seems to have made efforts to make up for the deficits of comparative advantage of these two sectors but they are apparently not good enough yet. The three sectors of Basic Metals, Chemicals, and Other Transportation are still strong but losing their grip. The remaining two sectors of Motor Vehicles and Fabricated Metals are again still strong but stagnant.

Figure 4.7. Korea's Relative Performance of Hamilton Index Industries (2020 LQ)

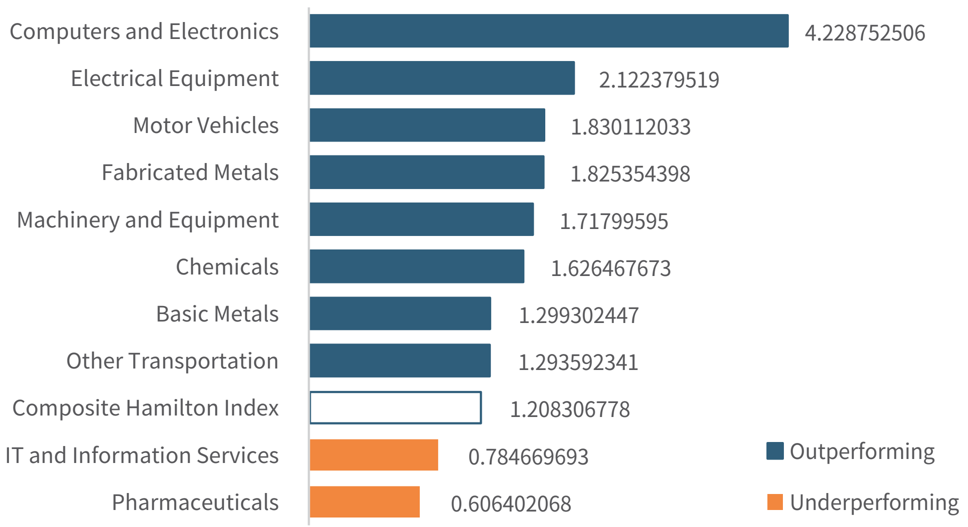


Figure 4.8. Korea's LQ Trends of Hamilton Index Industries

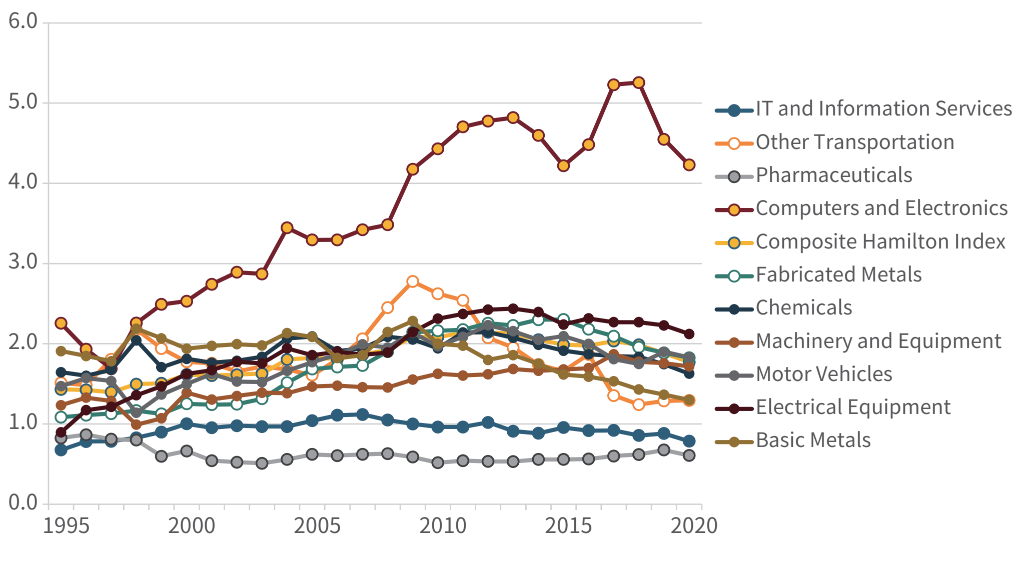
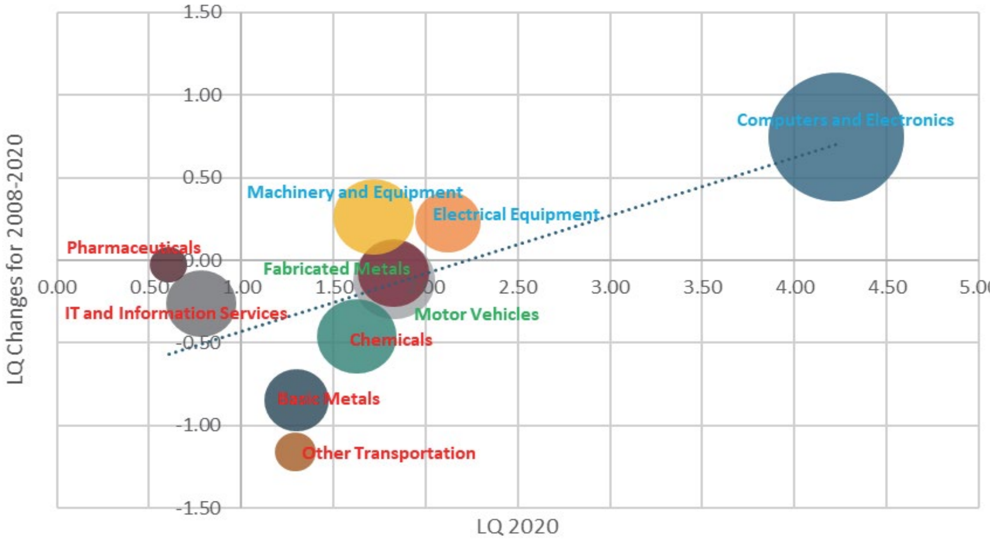


Figure 4.9. Korea's Relative Performance Changes during 2008-2020 (Bubble-scaled by 2020 Output)



2. Evolution of Science and Technology Innovation Policies

2.1. Institution Building

South Korea's Science, Technology, and Innovation (STI) policy has evolved through three phases since the 1960s (Ha et.al., 2019). The 1960s and 1970s were the foundation period, shaping the direction and characteristics of STI; the 1980s and 1990s were the high-speed growth period, with the diversification and multilayering of the NIS; and the 2000s and present are the advanced economy approach period, with the country gaining the capacity to compete equally with advanced economies.

Specifically, looking at the direction of Korea's major S&T policies, the 1960s and 1970s can be seen as a period in which the government set the primary goal of S&T policies to support economic growth and industrial development rather than focusing on the development of S&T innovation. Initially, the government took the lead in driving S&T innovation, but ultimately, the goal was set to transition to a private sector-led system with private companies as the centerpiece. In the 1980s and 1990s, the government greatly expanded its R&D resources to accelerate the development of technological innovation. The breadth and depth of R&D activities were greatly expanded through the upgrading of R&D capabilities, securing independent scientific and technological innovation capabilities, and diversification in many areas of R&D through developing multi institutions and layers. This was also the period when various measures were taken to support the R&D activities of private companies and to internationalize R&D in order to grow private companies into R&D centers. From the early 2000s to the present, Korea has been actively promoting the discovery of future growth engines and expanding its efforts to challenge the global frontier of science and technology innovation. The role of science and technology innovation is expanding from the traditional focus on economic development to contributing to social development.

2.2. History of Innovation Policy Reform

Reflecting the changing times and environment, the Five-Year Plan also showed the evolution of policies, with policy sectors emerging, growing, and disappearing according to their policy importance. From the 1960s to the mid-80s, the government strategically supported the import and improvement of technology from abroad for industrialization and the development of strategic industries to expand exports, and in the 1980s, it promoted a technology drive to catch up with advanced countries. In the 1990s, there was a shift from state-led development to private-led development, and government policies focused on strengthening the technological innovation capabilities of private companies and advancing the technology development support system. In the 2000s, support for small and medium-sized enterprises (SMEs) with weak competitiveness compared to large enterprises was intensively expanded.

2.3. Current Framework of National Innovation Strategy

2.3.1. Changing Environment and Goals

The U.S.-China strategic competition and the post-COVID-19 economic and social changes have occurred, and new global issues such as climate change and digital transformation are emerging. In order to respond to national issues, major countries such as the United States, China, the EU, and Japan are proposing the direction and establishing the promotion system of science and technology-based innovation policies that link and utilize not only technology development but also policy instruments in each field of society.

Table 4.3. Scopes of the Fifth Basic Plan of Science and Technology Policy

Sector	Current Status	Outlook
Technology	Intensifying U.S.-China Competition for Technological Supremacy	Technology blocs centered on trust and value, expanding technology regulations
Economy	Fragmentation of global markets, upheaval of industries and jobs	Widening gap between countries, deepening polarization within economy
Society	Entering the era of demographic cliff and digitalization	Realization of regional disappearance, expansion of social conflicts
Environment	Carbon neutrality, increasing natural disasters	Collective efforts to preserve the environment and respond to crises

Source: Ministry of Science and ICT (2022).

Table 4.4. Directions of the Fifth Basic Plan of Science and Technology Policy

	Existing S&T Policy	STI Policy
Policy Direction	Centered on development and promotion of S&T	Centered on solving national and social issues
Policy Objectives	Focus on quantitative inputs and outputs (Doubling the investment in basic research)	Focus on qualitative effects of policies (Increase GDP by 1 billion won per 100 million won of R&D investment)
Policy Scope	R&D-oriented policy measures (Support for science and technology education and research personnel)	Include both R&D and non-R&D (Support for science and technology education and research personnel + Foreign visa, university management innovation, new recruitment tax credit, etc.)

Source: Ministry of Science and ICT (2022).

In the face of increasing uncertainty in the global market, the governments of major countries such as the United States, Germany, Japan, and China have recognized the speed of innovation as a driver of national development and economic and social transformation, and have announced national-level development strategies. In response, the Korean government recently announced the national strategy for the development of science, technology, and Innovation, which includes measures for innovation in all sectors of the country and society while upgrading the existing science and technology policy by expanding the outer perimeter of the policy.

2.3.2. Long-term STI Vision

Korea develops long-term S&T visions approximately every ten years. The S&T Future Vision for 2040, introduced in 2010, and the Long-term Vision for S&T Development by 2025, introduced in 1999, are examples of earlier visions. Launched in 2020, the current vision is called Innovate KOREA 2045 - Challenges and Changes for the Future (henceforth, "Innovate KOREA 2045"). After consulting with the line ministries and an ad hoc body called the Future Strategic Body 2045, which was made up of about 20 professionals from industry, academia, and research institutes, the Science, Technology, and Innovation Office (STI Office) developed it. The current vision sought to establish connections between the Going Together Hopeful Korea 2030 vision, which was established in 2006, and the 2045 Vision for Innovative, Inclusive Growth, which was announced in 2019. Both visions focus on the economy and society as a whole, but they also highlight the significant role that science and technology play in advancing the inclusivity and sustainability of economic growth (MSIT, 2020). The goal of these documents, which span 25 to 30 years, is to offer long-term direction for S&T mid-term strategies and plans, which are created every five years, especially the S&T Basic Plans.

The long-term desired orientations for Korean society are outlined in Innovate KOREA 2045, together with the S&T problems that must be overcome in order to bring the vision to fruition. It identifies eight primary "challenging tasks" for the next 25 years, encompassing both short-term problems (such as the COVID-19 pandemic and the climate challenge) and long-term problems (like space exploration). In order to accomplish these goals, the vision maps sixteen "directions for technology development" over three distinct time horizons: short-term (less than five years), mid-term (about ten years), and long-term (more than twenty years). Examples include human space travel, AI semiconductors, brain-to-brain communication, and autonomous robots for disaster relief. The vision acknowledges that in the rapidly evolving world, the government's conventional method of choosing potential technology areas is no longer effective. Rather, it highlights the government's responsibility in determining and outlining the major issues of national concern and assisting different innovation players in creating the required technologies and leading the way in innovation.

Eight S&T "policy directions" are issued in response to the eight difficult challenges. For example, one of these policy initiatives is to replace the fast-follower research model with a "challenge-led creative research" model. Another advocated for a change in focus from "research to develop technologies" to "research addressing social challenges." Additional priorities include helping people reach their full potential, investigating novel forms of collaboration between the public and private sectors to open up markets, establishing regional ecosystems and clusters, utilizing science and technology in the public sector, enhancing Korea's position as a global leader in certain fields of science and innovation, and utilizing foresight to inform STI policy (OECD, 2023).

2.3.3. S&T Basic Plan

The S&T Basic Plan is a comprehensive strategy document that provides general guidelines for all ministries, including those in charge of R&I policy in and of itself and sectoral ministries when they formulate their own STI plans and strategies. The Presidential Agenda, which was introduced earlier in the policy cycle than the Basic Plan, is in line with the Basic Plan and provides more detailed guidelines for achieving it.

Some significant developments in the past have been prompted by and given legitimacy by this broad strategic framework, which is mirrored in and enhanced by area-specific strategies and plans. Most notably, there was a shift to a post-catch-up STI system that included significant funding increases for basic research and associated reforms.

Another example of Korea's audacious action is the 150% rise in government-funded

R&D spending during a ten-year period, from 2005 to 2015, which resulted in one of the highest R&D intensities globally (OECD, 2021). Additionally, proactive steps were taken to assist the development of new sectors. The assistance given to the biotechnology industry since the early 1990s, when dedicated R&D programs were established in close collaboration with the private sector, is one noteworthy example. Significant growth and societal effects, such as home remedies for some health and aging issues, have come from this.

In keeping with the overarching goal of creating a more inclusive STI system, the Basic Plans are organized along broad strategic directions and matching policy areas that are increasingly focused on resolving societal challenges. The broad orientations of the Basic Plans are complemented with more or less concrete "agendas" that are to be implemented by various policy bodies across the entire government structure, in contrast to the majority of western STI strategies that only include objectives and targets, followed by an action plan in the best-case scenario. As a result, the Korean Basic Plans serve as both an action plan and a mid-term strategy framework.

In response to national socioeconomic concerns such as supply chain management, climate change, low birth rates, and technological predominance, the Fifth Basic Plan was unveiled in 2022 and will run from 2023 to 2027. The Fifth Basic Plan is organized around three primary strategic thrusts and the requirement to continuously improve national STI capacity generally in order to address these issues:

- Transforming the S&T system for qualitative growth: Specific tasks and deadlines are established to solve the country's problems, and a "mission-driven R&D innovation system" is established to achieve them, focusing policy capacity on areas that require the most urgent response, such as fostering national strategic technologies and achieving carbon neutrality by 2050.
- Strengthening capacity-building ecosystems for open innovation: create a public-private consultative body to increase the private sector's participation in policymaking on a regular basis, and an innovation capability assessment system will be established to provide customized support for each company's capabilities, resulting in a science and technology innovation ecosystem centered on the private sector.

- Resolving national challenges and preparing for the future based on S&T: Solve national economic and social challenges such as carbon neutrality, digital transformation, and disasters/crises using science and technology, and respond proactively to future difficulties that directly affect national survival, such as supply chain/resources and space/ocean.

Each strategy thrust includes several implementation projects (each with five to seven detailed tasks and subsidiary action initiatives) to carry out the policy directions. The supply chain and trade; rising technology; diplomacy and security are the three criteria used to determine the 50 key technologies and 12 important technological sectors that are included in the 5th Basic Plan. The government will provide these technologies with increased support and investment in accordance with the strategic roadmap, and R&D funds will be allocated according to a mission-oriented funding distribution mechanism. Intense efforts will also be made to fortify private and international alliances. Ten projects are scheduled to be launched in 2023, starting with advanced small modular reactors (SMRs) and quantum technology initiatives.

Finally, the Fifth Basic Plan establishes measurable goals for a number of significant metrics. For example, the goal of having 4.8% of the top 1% cited publications by 2022–2026 is 1.27 percentage points more than the goal of 3.53% during the 2015–2019 period. The goal of increasing the number of triad patents from 3,057 in 2019 to 3,500 in 2027 is an illustration of an aim that is comparable (increasing the world-class strategic technology areas from 3 to 8, increasing the export market share in high-tech industries from 7.5% to 10%, enhancing the OECD Better Life Index ranking from 32^{nd} the 20^{th}).

3. Actors and Inputs of the National Innovation System

3.1. Government[2]

In order to better comprehend how much the current system is influenced by its past, this section outlines the history of the establishment of the Korean STI governance structure.

2. This sub-section is written based on the consultation with Dr. YEON Wonho

The evolution of Korea's STI governance system may be divided into three major phases. This analysis demonstrates the strong centralized governance and top-down policies of the government that have been essential in steering the contribution of STI to Korea's impressive growth during the first period of catch-up. During the post-catch-up period (200–22), this structure has been replaced with extensive centralized coordination and planning procedures. Korea is currently transitioning to a new sustainable growth model, to be led by a reformed STI governance system, as it enters a third stage of development in response to new economic and societal problems.

3.1.1. Rise of Self-governing Innovation System (1962-2000)

The five-year national economic growth plans from 1962 to the 1990s were one of the plans that most clearly outlined the national orientations for STI development. The significance of these national plans' involvement in obtaining and learning from foreign technologies in specific industries has been well documented as in Pirie (2008), despite the fact that their reach went well beyond technological innovation. The five-year Technology Promotion Plans were one of the other national dirigiste planning tools. Government STI plans and interventions continued to be heavily dependent on business demand and remained under the purview of economic and industrial development policies, despite their important roles in the gradual construction of a more self-sufficient STI system that relied upon national knowledge and innovation resources and capabilities. Important foreign technologies were also absorbed by the government research institutes (GRIs) and passed on to big Korean companies. State authorities also provided major direction and assistance to private companies through protected laws, targeted industry-specific licenses, and subsidized loans. By means of long-term production networks and backward links with nearby small- and medium-sized businesses (SMEs), the advantages of these new technologies and the learning that goes along with them have partially permeated other sectors of the industry. Although the initial Korean Technology Development Promotion Policy was in effect from 1962 to 1966, until the 1980s, the government's role in promoting research and innovation (R&I) activities was still ingrained in the country's development strategy. During this decade, more independent STI policies—that is, policies that remain linked to other sectors of the economy but are propelled by a unique approach to fostering knowledge and innovation with appropriate decision-making hubs, intervention techniques, and resources—began to take shape. Based on the Technology Development Promotion Act, the Ministry of Science and Technology, the former body in charge of science and technology (S&T), launched the first national R&D program, known as the Specific R&D Program, in 1982. The goal of this initiative is to foster the development of core technologies and strengthen the nation's S&T capabilities. Simultaneously, the government implemented a novel tool, large precompetitive consortia, modeled after the United States and Japan, that brought together numerous firms and concentrated on specific industrial technologies, like semiconductors and a range of information technology (IT) technologies. Modeled after the Japanese Technological Research Associations, the first was established in 1982 as the Industrial Research Association. Others, particularly those in sectoral ministries, quickly trailed after (Sakakibara and Cho, 2022).

To create the domestic R&I knowledge foundation required to support cutting-edge technological development, a greater focus was placed on fundamental research in the second half of the 1990s (Yim and Kim, 2005). These investments were augmented by initiatives to boost the commercialization of research. Launched in 1992 and ending in 2001, the Highly Advanced National (HAN) Project (sometimes called the G7 Project) was a response to the need for a more coordinated and national R&D program. It was the country's first mid- to long-term R&D plan. It was considered crucial in promoting industries such as semiconductors, numerous IT sectors, electronics, and autos, where Korean businesses are today world leaders.

The President, the Presidential Secretary's Office, and a number of high-ranking government officials headed the governance structure of the fledgling STI system during this initial phase, and especially up until the 1990s, which supported the gradual enhancement of domestic R&D capacities (Seong, 2011).

In addition, implementation was centralized inside the Agency of Science and Technology, which oversaw all national R&D initiatives and served as the forerunner to the research-related ministries. The first coordination council, known as the Science and Technology Review Committee, was established in 1973 with the prime minister serving as its chair and consisting of 14 ministers. Its activity in the 1970s and 1980s was little. However, when the system's size and breadth grew quickly in the first half of the 1990s, the requirement for efficient coordination grew dramatically. It demanded a more complex system of governance, complete with a variety of specialized roles and agencies inside the government that make decisions. The rise in private R&D investment and the number of sectoral ministries (agricultural, transportation, health, land and construction, etc.) that began making sizable investments in R&D activities were two indicators of this system's expansion. Growing problems with inter-ministerial coordination resulted from this (Oh and Lee, 2013). Concerns ranged from ministries' tendency to copy and duplicate each other's programs rather than starting their own based on sound strategy and understanding of stakeholders' (especially in industry) needs in their policy area, to overlaps between ministries' programs and conflicting policy objectives in a context of intense competition for power and budget (Hong, 2005).

3.1.2.Development of STI Governance System (2001–22)

At the start of the new millennium, the government undertook a drastic overhaul of the governance structure due to the mounting demands for more strategic steering in a dynamic national and international setting, as well as an increase in coordination challenges. These reforms were both made possible and essential by the backdrop of notable growth in government R&D spending, as more and more programs and projects needed to be planned, managed, and assessed. The organizational structure and legal foundation were established in less than five years, and they have undergone numerous revisions since then. The Framework Act on Science and Technology was enacted in 2001, the first five-year S&T Basic Plan was introduced in 2002, the Ministry of Science and Technology was established in 1998 (building on the former Ministry of Science and Technology), an executive office called the Science, Technology and Innovation Office was established in 1999 to oversee an expanding range of STI governance functions, and the Ministry of Science and Technology was renamed the National Science and Technology Council (NSTC) in 1998.

One of the most important steps toward developing the Korean STI governance framework was the creation of the Framework Act on Science and Technology in 2001. It gave the primary organizations and systems the legal foundation they needed to centrally coordinate all STI-related policies. Since then, it has undergone numerous revisions and has been put into effect by a number of new or updated funding organizations, enforcement orders, rules, and initiatives. It has also gradually been supplemented by a number of other laws in particular fields (assessment, agency administration, etc.).

A significant step toward creating an innovative system was taken in 2002 with the introduction of the first five-year S&T Basic Plan, which ran from 2002 to 2006. This plan had its own strategic orientations that were derived from the system itself and were carried out by appropriate authorities using their respective modes of intervention. The Basic Plan was the first to cover and incorporate all of the various aspects of the 2002-enacted Korean National Innovation System Model into a single, cohesive framework. These aspects included managing national R&D programs, raising public awareness of STI, developing R&I human resources and skills, enhancing technology transfer, and fostering international research collaboration.

The legal and strategic underpinnings of the system were established by the Framework Act and Basic Plan, but strong institutions were required to carry out STI governance in reality. This void was quickly addressed with the establishment of the NSTC, a new and more potent coordination body, and subsequently the STI Office. With the exception of brief stints when their scope was altered and their size was reduced, these two organizations enjoyed a major increase in their rights during multiple waves of reform.

Even after these changes, coordination was thought to be inadequate. The 2000 World Bank assessment in Dahlman and Anderson (2000) and the Korea Innovation policy evaluations conducted by OECD (2009, 2014) also addressed issues related to policy coordination between several ministries. In order to address these problems, new laws and procedures were established (such as those for observing the plans and programs of sectoral ministries for creating the R&D budget), and central administrative and deliberative institutions were given more authority and credibility. Additionally, in an effort to enhance coordination and/or streamline organizational structures, ministries, and agencies have been combined or reorganized. For example, the Ministry of Education (MOE) and the Ministry of Science and Technology (MOST) combined to become the Ministry of Education, Science and Technology (MEST) in 2008. The

2008 establishment of the Ministry of Knowledge Economy (MKE), which combined elements of the Ministry of Information and Communication (MIC), the Ministry of Commerce, Industry and Energy (MOCIE), and MOST, was also noteworthy. In order to strengthen the knowledge and technological foundation of industries in key industries and create new growth opportunities, this “super ministry,” which was in operation until 2013 when it was dissolved, sought to have a more integrated policy structure and to increase cooperation between policy portfolios (not least around semiconductors, IT and biotechnology).

A number of structural modifications were also made to agencies. For example, the merging of four energy research and development organizations resulted in the establishment of Korean Energy Technology Evaluation and Planning (KETEP). Furthermore, GRIs have been moved around among different research councils and ministries, but since 2014, the organization appears to have stabilized a little.

In addition to these structural adjustments, Korea established a distinctive governance framework in the 2000s to direct, oversee, and carry out an expanding range of STI government initiatives involving over 20 ministries and several agencies. In order to balance this growth with a legacy of strategic integration from the catch-up period model, the government gave central executive and coordination bodies a strong mandate and added more mechanisms to the entire government structure for coordination, budgeting, and monitoring, as well as rules and guidelines.

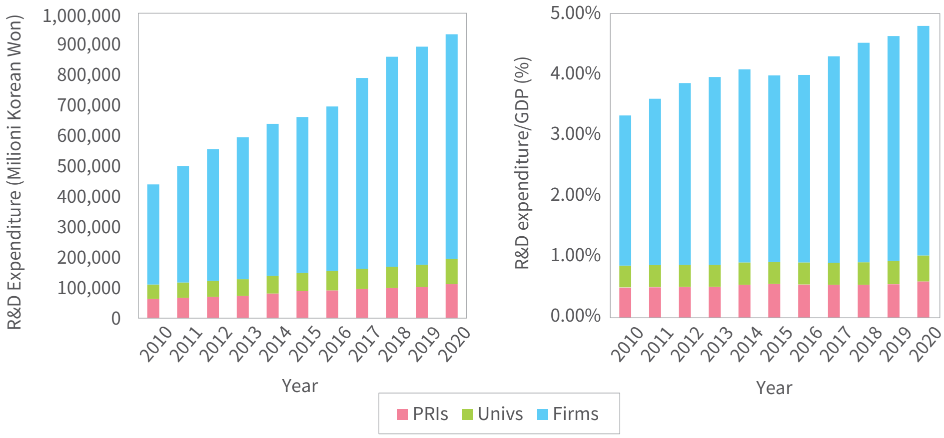
3.1.3. Reliance on Central STI Institutions

Two primary organizations collaboratively oversee and/or carry out the majority of the core duties related to science, technology, and innovation, including establishing objectives, offering guidance, and conducting monitoring and evaluation. The two entities involved are: (1) PACST, which serves in a consultative and advisory capacity; and (2) the STI Office, which has the authority to make decisions and carry out executive functions. Throughout the last few decades, these organizations have undergone numerous alterations in their composition, mandate, institutional standing, and place within the STI governance system.

3.2. Firms

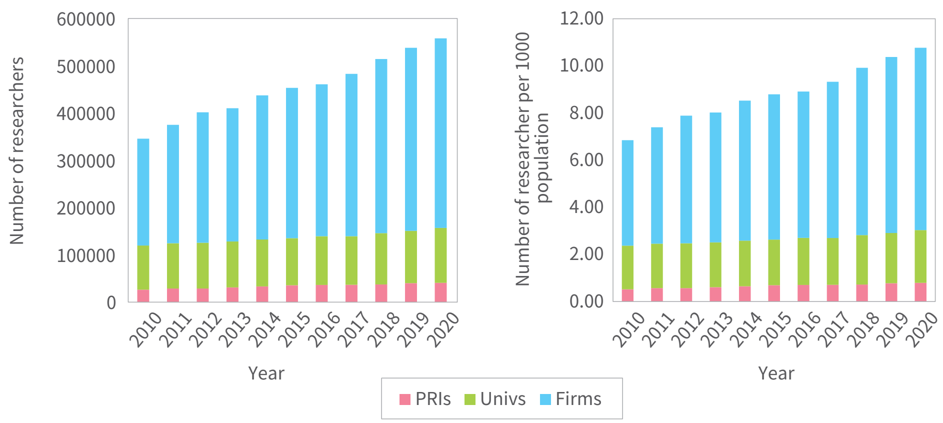
Firms play a pivotal role in Korea's National Innovation System (NIS). Over the past decade, private sector R&D investments have accounted for 70% to 80% of Gross Expenditure on Research and Development (GERD) in Korea, totaling approximately 4% of the country's Gross Domestic Product.

Figure 4.10. R&D Expenditure by Type of Actor in Korea



Source: MOTIE and KIAT (2022)
Legend Note: "PRIs" for Public Research Institutions, "Univs" for Universities

Figure 4.11. Number of Researchers by Actor



Source: MOTIE and KIAT (2022)
Legend Note: "PRIs" for Public Research Institutions, "Univs" for Universities.

The composition of researchers by the types of organizations underscores the significant role of firms within the Korean NIS, in terms of labor contributions to national-level innovation activities. In 2010, about 69% of all researchers in organizations in South Korea were employed by firms, a figure that increased to 72% by 2020. During this period, the proportion of researchers in universities and PRIs decreased from 27% to 20% and from 7.6% to 7.3%, respectively. It is noteworthy that the number of corporate researchers has markedly risen over the past decade. In 2010, there were 4.48 corporate researchers per 1000 people, a figure that grew to 7.74 by 2020.

Firms' R&D investments have primarily focused on the development phase of the R&D process, expanding into the applied research stage, which increased from 16.6% in 2010 to 20% in 2020. In contrast, the share of R&D investment in basic research steadily declined, decreasing from 13.9% in 2010 to 10.5% in 2020. This shift reflects a trend observed in the United States as well (Arora et al., 2018), where firms have redirected their R&D investments from the pursuit of scientific discoveries to the development of commercially viable technologies.

Firms innovate not only through internal R&D but also by sourcing technology through external R&D or integrating external resources into their internal R&D processes. According to statistics between 2010 and 2020, firms in Korea allocated 93% of their R&D budget for internal R&D. Although this figure dipped to 89% in 2017, it rebounded to 92% in 2020. This trend suggests that the innovation activities of Korean firms are increasingly performed through internal R&D.

In Korea, large companies are at the forefront of driving innovation within the country's business sector. The top 10 firms, in terms of R&D expenditure, contribute to over 50% of the total private sector R&D investment, equivalent to 36% of the nation's GERD. This percentage has steadily increased over the past decade. In 2020, among the top 1,000 firms investing in R&D, 163 were large companies, collectively committing around 44,000 billion Korean Won to R&D. This amount represents 80% of the R&D spending within the business sector by these top 1,000 firms.

Table 4.5. **Destinations of Firm R&D in Korea**

Year	Basic Research (%)	Applied Research (%)	Development (%)
2010	13.9	16.6	69.5
2011	13.3	17.3	69.4
2012	13.1	17.0	69.9
2013	13.1	17.1	69.9
2014	13.1	17.0	69.9
2015	12.4	19.3	68.2
2016	11.9	20.7	67.4
2017	10.6	20.3	69.2
2018	10.6	20.3	69.1
2019	10.6	21.2	68.2
2020	10.5	20.0	69.5

Source: MOTIE and KIAT (2022)

The innovation efforts of firms in Korea have centered on the manufacturing sector. From 2010 to 2020, the business R&D in the manufacturing sector accounted for more than 85% of the total R&D investment by firms. In contrast, firms' R&D investment in the service sector remained at a steady 10%. This manufacturing sector-focused R&D by firms in Korea can be attributed to historical factors, particularly the country's decades-long economic growth and planning centered around the manufacturing sector.

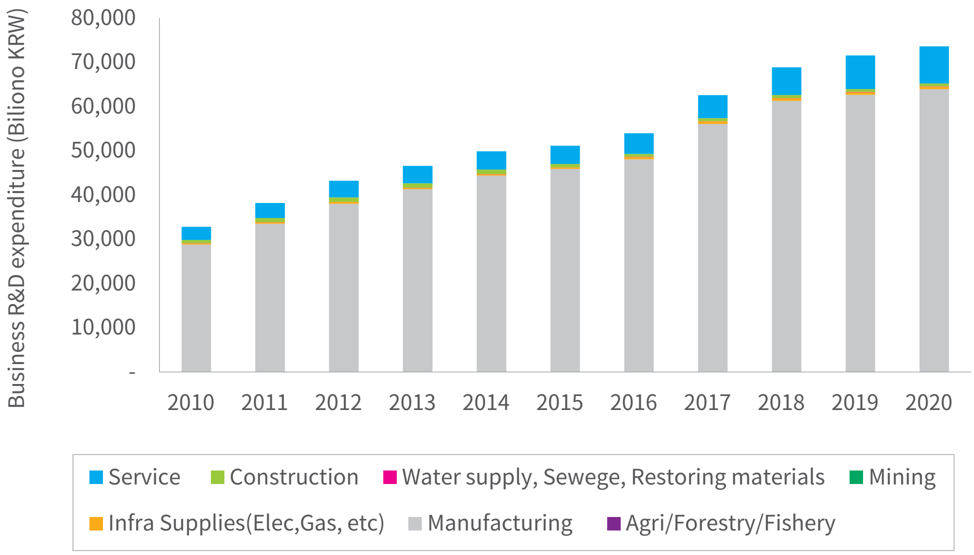
Detailed statistics on the destinations of firm R&D investments within the manufacturing sector show a notable concentration of firms' innovation efforts in the following three domains:

- Electronics – Firm's R&D investment in this domain takes 50% of the total business R&D investment in the manufacturing sector. The predominance of this sector is attributed to the presence of several R&D-intensive large electronics firms in Korea, such as Samsung and LG.
- Car Manufacturing - Car manufacturing comprises 18% of the business R&D investment within the manufacturing sector. Industry giants such as Hyundai and

Kia Motors are the key firms.

- Chemicals manufacturing - The chemical industry accounts for 9% of the business R&D investment in the manufacturing sector. LG Chemicals, SK Chemicals, and Hyosung Chemicals are examples of the major firms in this industry.

Figure 4.12. Industrial Sector Distribution of Firm R&D Investment



Source: MOTIE and KIAT (2022)

Firms indeed contribute to innovation through various avenues, including the development of new products, enhancements in production processes, workforce training, and active participation in the technology market as both buyers and sellers of technology.

According to the 2020 Korea Innovation Survey, approximately 12% of surveyed firms in the manufacturing sector and 5% in the service sector undertook product innovation between 2017 and 2019 (STEPI, 2021a). Large firms, once again, played a significant role in these innovation activities, with half of the firms engaged in product innovation in both the manufacturing and service sectors falling into the large firm category.

As of 2021, there are 44,069 operational corporate R&D centers, employing 383,682 corporate researchers. The number of corporate R&D centers in Korea nearly doubled in the last decades. This increase is primarily attributed to large firms. The number of R&D centers affiliated with large firms increased from 1,415 in 2011 to 2,143 in 2020, and the number of corporate researchers hired by large firms grew from 110,104 to 160,084 during the same period, representing one-third of all corporate researchers in Korea.

3.3. University

Universities in Korea are categorized into national/public and private universities. As of April 2023, 34 national universities (along with one public university) and 155 private universities are in operation, collectively educating over 1.8 million undergraduate students (KEDI, 2023). National/public universities in Korea are established and operated under the Higher Education Act. They receive government financing and are administered by the Ministry of Education. In contrast, private universities are governed by the Private School Act, which allows non-profit foundations to establish universities with government approval.

In addition to national/public and private universities, Korea has five science and technology-oriented research institutes that offer educational services. Four of them receive government funding and are collectively known as ISTs (Korea Advanced Institute of Science and Technology (KAIST), Gwangju Institute of Science and Technology (GIST), Ulsan National Institute of Science and Technology (UNIST), and Daegu Gyeong-buk Institute of Science & Technology (DGIST)), and one remaining is POSTECH. The Ministry of Science and ICT serves as the administrative governmental body for these four ISTs while POSTECH is a privately founded science and technology-oriented university funded by POSCO, a steel manufacturing company.

These five science and technology-oriented institutes provide science and technology-focused graduate and undergraduate educational programs, exhibiting their strong research capabilities. As of 2022, the four ISTs and POSTECH are educating over 8000 undergraduate and about 14,000 graduate students. In 2022, KAIST, UNIST, and POSTECH were ranked in the top 50 universities in the US NEWS World University Rankings in multiple S&T research areas.

In Korea, all males aged 18 and above are required to serve in the national military. This mandatory national military service requirement has become the ground for institutionalizing a unique labor market for researchers and graduate students majoring in science and technology at universities, known as the "Military Exemption for Research Personnel." Instead of serving in the Korean Army, Navy, or Air Force, researchers and university students whose fields of study are related to science and technology have the option to complete their military service by working at PRIs, firms designated by the government, or by pursuing a science and technology-related advanced degree program in Korea. This institutionalized labor market is one of the unique features of the Korean NIS as it works as a channel of supplying science and technology professionals to both industry and research institutes. However, it must be noted that this unique S&T labor market could induce economic inefficiencies in labor allocation. This institution mandates highly skilled S&T individuals to work in specific sectors or companies designated for a fixed period, which disrupts the natural market-driven distribution of talent, where skilled workers would otherwise be employed where their expertise is most needed and valued. This institution, while preserving critical expertise within national borders, may lead to a suboptimal distribution of skilled S&T professionals, potentially stifling innovation.

As of 2022, 2,400 researchers and graduate students majoring in science and technology are eligible for the Military Exemption for Research Personnel. The government has approved 1,914 companies, 185 PRIs, and 257 universities (including university-affiliated research centers) to hire these researchers and students to fulfill their national military service (KITA,2023).

Within the higher education system in Korea, more than 150,000 students have earned undergraduate-level STEM degrees, and this number has steadily increased over the past decade (Ministry of Science and ICT, 2022b).

Universities have been the second-largest contributors in terms of the size of R&D investment, accounting for approximately 10% of GERD in Korea (0.4% of the GDP as of 2020). While the absolute amount of R&D investment by universities has increased over the past decade, their share of R&D investment in GERD has steadily decreased due to the significant expansion of corporate R&D investments.

Funding for university R&D primarily originates from the government. As of 2020, around 82% of university R&D investments were government-funded, with funding from the private sector accounting for 14%. Notably, government funding has been steadily increasing over the past 20 years, while private sector funding for university research has increased since 2007.

In contrast to corporate R&D, university R&D appears to be evenly distributed across the three stages of the R&D process. This is evident in the distribution of R&D investments, where the proportions for basic research, applied research, and development are 37.5%, 30.8%, and 31.8%, respectively.

In addition to the size of R&D investments made by universities, it is also important to consider the supply of S&T expertise by universities for a more comprehensive understanding of the role of universities in NIS. According to national statistics, there are 115,924 researchers employed by universities as of 2020, accounting for 21% of all active researchers in Korea (2.24 researchers per 1000 people). Although the absolute number of researchers has gradually increased over the past 20 years, the proportion of university researchers has decreased from 32% in 2000 to 21% in 2020. In contrast, the share of corporate researchers has increased from 59% to 72% during the same period. This suggests that more researchers are increasingly pursuing careers in the private sector rather than academia.

3.4. Public Research Institutes

Public Research Institutes (PRIs) are designated organizations conducting R&D with governmental funding. PRIs in Korea can be roughly categorized into two groups based on the administrative body of the Korean government.

The first group consists of 24 PRIs operating under the administration of the National Research Council for Economics, Humanities, and Social Sciences. PRIs in this category focus on social science research and provide policy analysis, evaluation, and recommendations for the Korean government. The Korea Development Institute (KDI) is an example. KDI, as emphasized in its mission statement, has played a significant role in implementing and evaluating various economic policies in Korea. It was a key contributor to developing and implementing a series of Korea's 5-year Economic Development Plans from the 1960s to the 1990s. KDI also established the KDI School of Public Policy and Management, a graduate school aimed at training researchers in planning and evaluating national policies across various fields, including economics, science and technology, and energy policy.

Another group of PRIs is governed by the National Research Council of Science & Technology, focusing on providing research functions for natural science and technology development with governmental funding (21 PRIs as of 2023). Examples include the Korea Institute of Science and Technology (KIST) and the Electronics and Telecommunications Research Institute (ETRI). In the 1960s, KIST concentrated on introducing and domestically producing various industrial technologies for Korean firms. For instance, in 1975, KIST developed Korea's first minicomputer and successfully produced the Pneumococcal vaccine in 1979. By the 2000s, KIST had reoriented its focus toward high-tech sectors, developing technologies such as the Fuel Cell Electric Vehicle system and spin-transistor technology in 2000. More recently, KIST has aimed to create original technology rather than just implementing existing technology locally. In 2013, KIST succeeded in developing flexible memory technology and shifting its institutional focus to the quantum-computing domain.

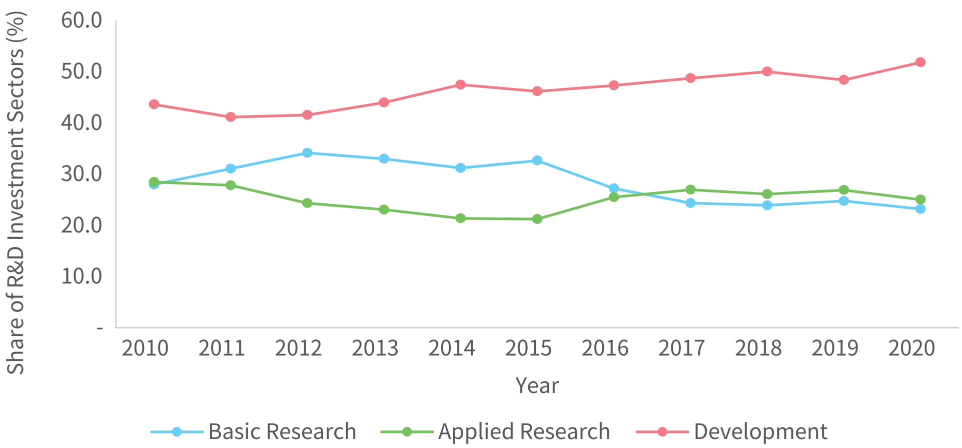
ETRI is another example of a PRI that plays a crucial role in the Korean NIS. Established in 1976, ETRI focused on electronics R&D, including semiconductors, computers, and telecommunications. In 2000, ETRI successfully introduced and commercialized Code-Division Multiple Access (CDMA) digital communication technology. This achievement marked the world's first commercialization of CDMA technology and significantly contributed to the growth of the telecommunications industry in Korea by inducing the expansion of mobile communication infrastructure and the introduction of mobile devices in Korean society.

PRIs, as key players in the Korean NIS, are well-documented for their active R&D investments. Over the past decade, PRIs have consistently accounted for approximately 11% to 15% of the GERD in Korea (about 0.6% of GDP as of 2020), with an annual growth rate of 5%. Similar to universities, the proportion of PRIs' R&D investment in GERD has gradually declined during the same period, mainly due to the disproportionate increase in corporate R&D investments. Statistics indicate that approximately 7% to 8% of the national-level R&D workforce is employed by PRIs.

The primary financial source for PRIs' R&D is governmental funding. Between 2010 and 2020, 95% of PRI R&D funding came from the government. Although PRIs in Korea have traditionally been seen as research organizations focusing on basic or applied research, recent statistics reveal a gradual shift in their focus toward the development phase with a consistent decline in the proportion of R&D investment for basic and applied research (Figure 4.13).

In 2010, researchers employed PRIs accounted for only 7.6% of all researchers in Korea (equivalent to 0.52 per 1000 people), and this figure slightly adjusted to 7.3% in 2020, demonstrating a relatively stable trend over the past decade.

Figure 4.13. PRI's R& D Investment Allocation



Source: MOTIE and KIAT (2022)

Some S&T-focused PRIs in Korea provide educational programs for graduate students through a joint graduate school designed for advanced degree programs. An example is the University of Science and Technology (UST), established in 2004. In this program, each PRI in Korea participates in providing an S&T-focused graduate program for master's and Ph.D. students. Principle Investigators (PIs) or senior researchers in the participating PRIs, typically holding doctoral degrees, become students' advisors and the enrolled students are encouraged to participate in government-funded research projects, with their advisors. The S&T workforce training programs offered by PRIs in Korea suggest that the roles of PRIs and universities seem to converge in Korean NIS, as both types of organizations serve educational and research functions.

4. Linkages of Innovation Actors

4.1. Firm-University Linkage

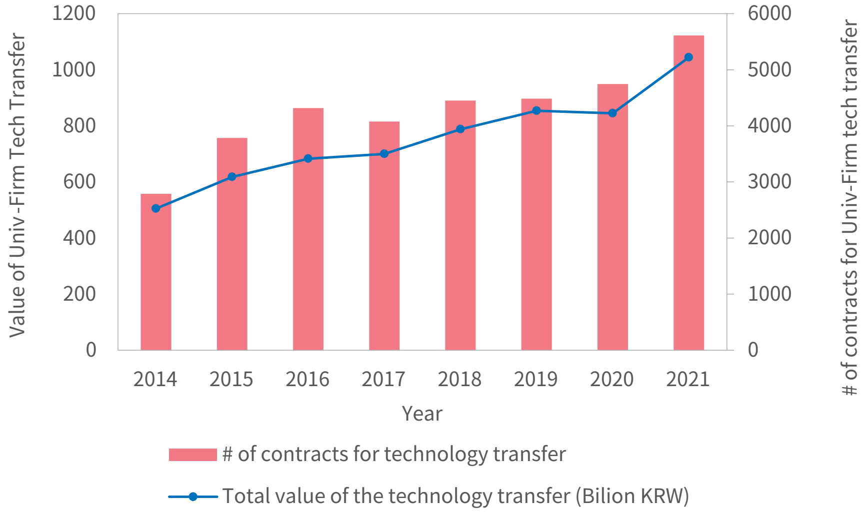
In NIS, firms and universities interact in various ways for innovation. The classic NIS literature focuses on four types of linkages: collaborative R&D, universities' provision of education programs for retraining corporate researchers/scientists, technology transfer, and university spin-offs (Friedman and Silberman, 2003; Kroll and Liefner, 2008; Siegel et al., 2003; Singh et al., 2015).

In Korea, universities and firms are increasingly collaborating on research and development (R&D). While governmental funding remains the primary source for universities' R&D initiatives, the private sector's contribution has steadily risen from 11% to 14% over the past decade (Korea Institute for Advancement of Technology, 2022). This demonstrates a growing partnership between Korean universities and businesses in both the academic and economic spheres. A notable example of this collaboration is the establishment of industrial scholarship programs. Several Korean firms, mostly those in the manufacturing sector, offer these scholarship programs, covering tuition and living expenses for graduate students specializing in science and technology-related disciplines, during their degree programs. In return, scholarship recipients commit to working for the sponsoring firm upon graduation.

Firms and universities form partnerships to retrain their corporate scientists and engineers. A unique institution that facilitates this collaboration is the "special contract department". This department is dedicated to educating engineers and scientists from the contracting company. The firm provides funding to the host university to operate the department and covers the tuition of the engineers and scientists in the program. The host university offers educational programs and academic advising services to the scientists and engineers from the contracting firm. The Department of Semiconductor System Engineering at Sungkyunkwan University, established and operated through a contract with Samsung Electronics, and the Department of Future Mobility at Seoul National University, established via an agreement with Hyundai-Kia Motors are examples of the special contract department. As of 2022, universities in Korea are operating 237 special contract departments with a total enrollment of 8,299 students, with steady growth over the past five years (Ministry of Education, 2023a).

Technology transfer is another major channel for interaction between universities and firms in the context of innovation. In Korea, firms and universities entered into approximately 5,000 technology transfer agreements in 2022, with a total monetary value exceeding 1,400 billion Korean Won (Ministry of Education, 2023b). Private universities accounted for 60% of these university-firm technology transfer agreements, while national/public universities were involved in 38% of them (the remaining 2% included technical colleges, etc.). The steady increase in the total value of technology transfers between universities and firms reflects the activated industry-academia for the commercialization of university knowledge.

Figure 4.14. University-Firm Technology Transfer

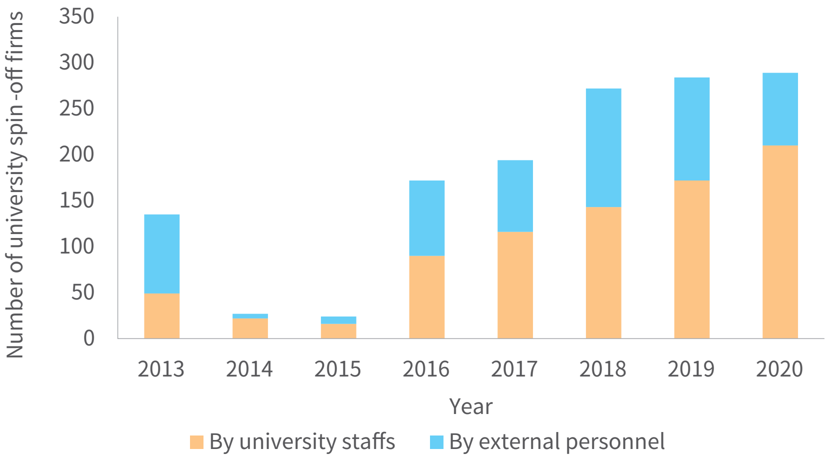


Source: MOTIE (2023)

Technology Licensing Offices (TLOs) in universities are dedicated organizations responsible for supporting and managing technology transfer activities conducted by faculty members and researchers. As of 2021, the number of employees in university TLOs in Korea reached 8,162, representing a steady increase over the past decade (National Research Foundation, 2022). This growth underscores the expansion and strengthening of TLOs' functions at universities to better facilitate their technology transfer activities.

Fourth, the creation of firms through university-based spinoffs is another vital channel for universities and firms to interact and contribute to national-level innovation. According to statistics reported by the Ministry of Education in Korea, the number of university-based spinoffs increased from 144 in 2013 to 289 in 2020. Most of these university spin-offs were founded by faculty, researchers, and administrative staff. Their share has steadily increased, rising from 40% in 2013 to 73% in 2020 (National Research Foundation, 2022). Furthermore, university students also actively establish firms. In 2015, 861 firms were founded by university students, and this number has steadily increased to 1,805 in 2020.

Figure 4.15. Number of University Spinoffs



Source: National Research Foundation (2022)

Table 4.6. **Number of Firms Founded by University Students**

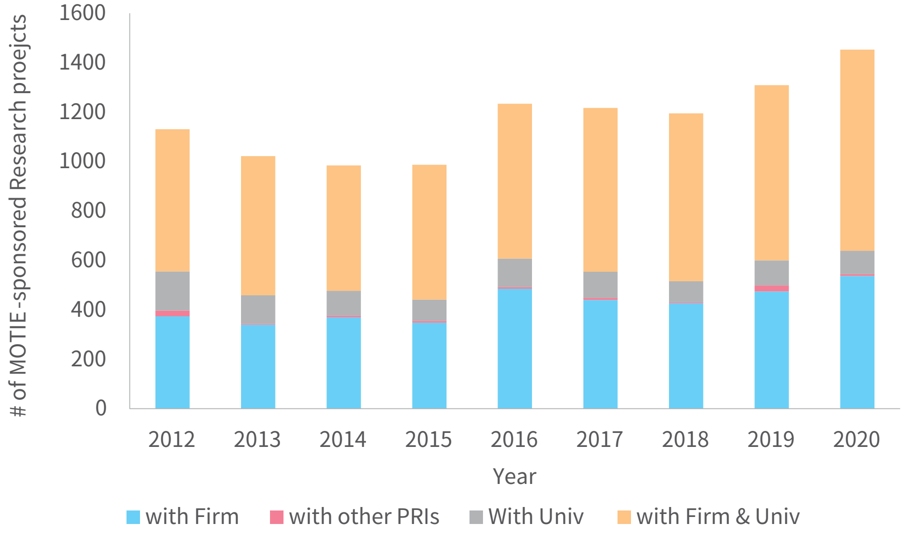
Year	# of firms	Total sales revenue (Million KRW)	Total # of employees
2015	861	8,310	280
2016	1,191	14,356	391
2017	1,503	20,172	406
2018	1,534	15,332	336
2019	1,624	16,409	355
2020	1,805	18,910	560

Source: National Research Foundation (2022)

4.2. Firm-PRI Linkage

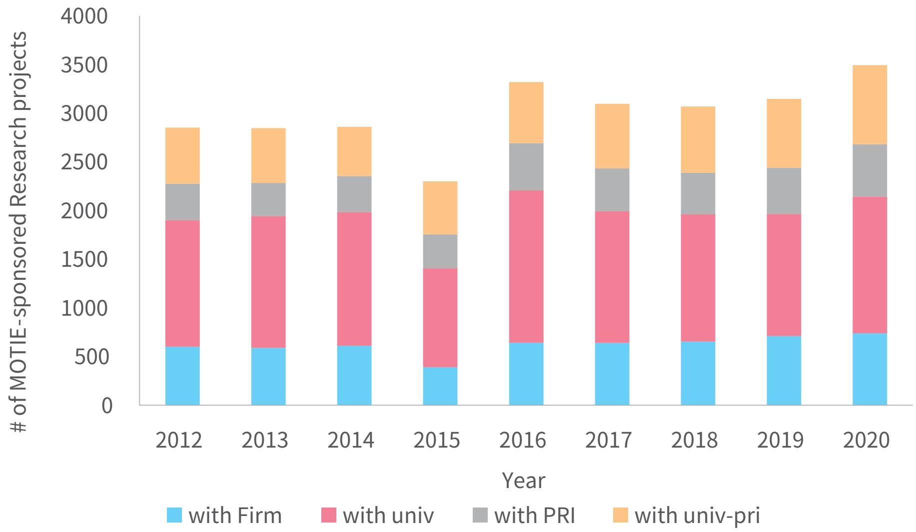
Compared to the active connection between universities and firms for innovation in Korea, the linkages between PRIs and firms are relatively weak. As mentioned earlier, government funding has consistently served as the primary source for PRIs' R&D investments, while the share of private sector funding (i.e., from firms) remains below 4%. The information regarding the number of collaborative R&D projects funded by the Ministry of Trade, Industry, and Energy (MOTIE) of Korea further indicates that PRIs and firms less engage in bilateral partnerships, but more engage in tri-parties collaborative R&D with the involvement of universities. Indeed, the statistics show that of all the PRI-involved collaborative R&D projects funded by MOTIE, those involving collaboration between PRIs and firms account for approximately 35%, while projects that involve universities, PRIs, and firms collectively make up 57%. A similar conclusion is reached from the firm's perspective. Among firms-involved collaborative research projects that were funded by MOTIE, the projects by bilateral involvement of firms and PRIs take only 15%, while joint research by university-firm-PRI collaborations make up about 24%.

Figure 4.16. PRI-involved Collaborative Research Projects Funded by MOTIE



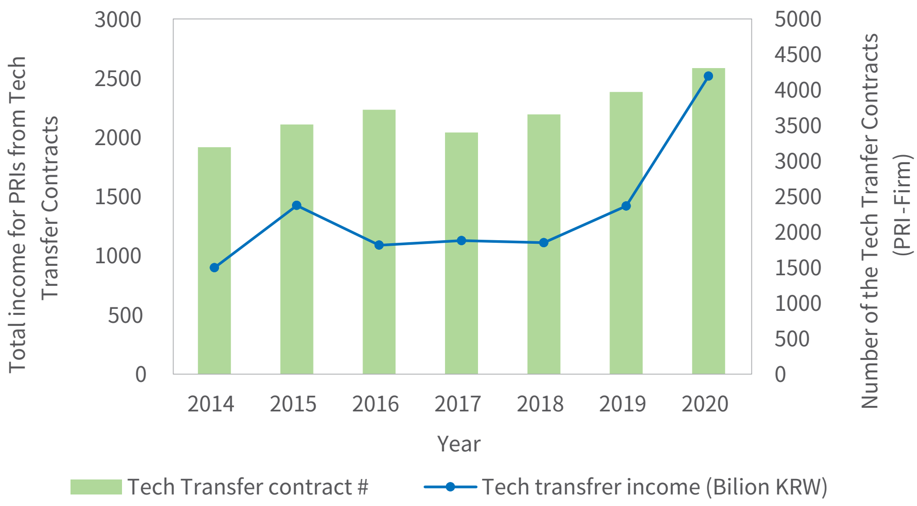
Source: MOTIE and KIAT (2022)

Figure 4.17. Firm-involved Collaborative Research Projects Funded by MOTIE



Source: MOTIE and KIAT (2022)

Figure 4.18. Number and Value of Technology Transfer Agreements by PRIs



Source: National Research Foundation of Korea (2022)

The total number of contracts for technology transfer by PRIs has steadily increased, and the total value of these technology transfer contracts appears to have rapidly grown over the past 8 years.

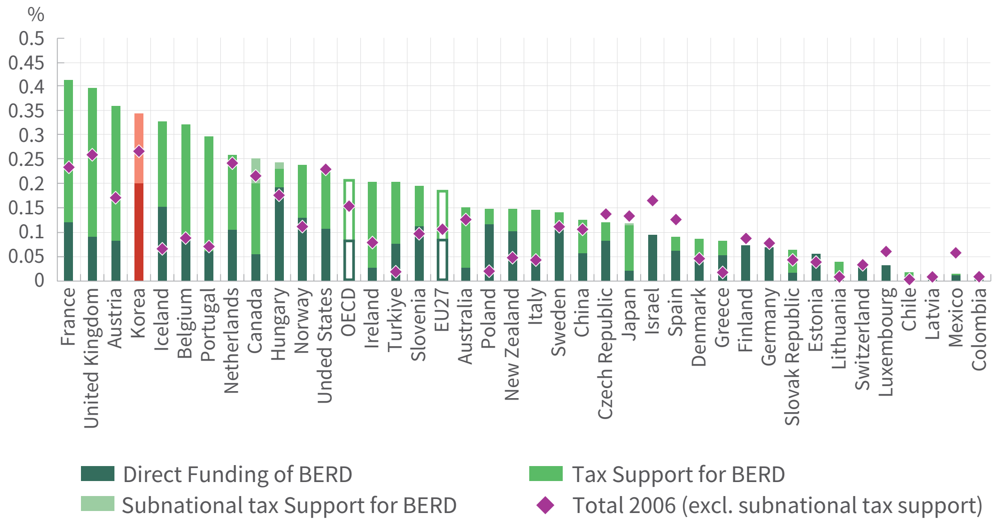
The UST, a joint virtual graduate school operated through cooperation among S&T-focused PRIs in Korea, also offers educational programs for corporate researchers and scientists through special contract departments, similar to universities. However, compared to universities, the size of the program is relatively small.

4.3. Government-Firm Linkage

Without committed government assistance, the advancements and rapid growth of Korean business innovation in particular fields would not have been conceivable. This section demonstrates how the Korean government's initiatives have contributed greatly to the growth of business innovation in Korea, while also recognizing the need to help small and medium-sized businesses (SMEs). This section concludes with a description of recent efforts to allay certain worries regarding the partial fragmentation of government assistance.

In 2020, Korea placed among the OECD countries that provide the largest level of total government support to business R&D as a percentage of GDP, at a rate of 0.29% of GDP (Figure 4.19). Most public support for business R&D is directed at SMEs. In 2019, the government financed 13.2% of all R&D conducted by SMEs. In contrast, the government financed only 1.8% of the R&D expenditures of large firms (MSIT and KISTEP, 2021). Heavy focus on SMEs in public support for business R&D applies not only to direct funding but also to tax support. In line with the government's direct financing of business R&D, R&D tax breaks for SMEs are much more generous than for large firms. Specifically, tax credits for large firms are capped at 2% of R&D spending, while there is no ceiling for the R&D tax credits for SMEs. As a result, the implied tax subsidy rate for profit-making SMEs was 26% in 2020, in contrast to 2% for large firms. Nonetheless, due to the dominant role of large firms in R&D spending in Korea, the share of the total amount of R&D tax credits given to SMEs among all R&D tax credits was only 40% in 2018 (OECD, 2022a).

Figure 4.19. Government Funding Tax Incentives Support to Business R&D (% Relative to GDP)



Source: OECD (2022[17]), R&D Tax Incentives (database)

Note 1: Data on subnational tax support are only available for a group of economies.

Note 2: For some economies where year 2020 data are not available, the nearest year data points are used.

Among the main OECD nations, Korea stands out for its emphasis on R&D tax benefits for SMEs. Large, industrialized nations, with the exception of the United Kingdom, offer large and small businesses essentially the same R&D tax advantages. In Korea, tax incentives gained significance in absolute terms between 2007 and 2019, while the proportion of taxes to direct support was relatively constant. Thus, business firms' taxable income deductions connected to research and development (R&D) totaled KRW 2.81 trillion in 2018 (MOTIE and KIAT, 2020).

In Korea, the government provides SMEs with a plethora of policy instruments, such as funding incentives for business research and development, preferential access to public procurement, company-size-based rules, and entire market segments set aside for SMEs. When considered separately, several of these policies might have some merit, but taken as a whole, they create a system that helps low-productivity businesses thrive in the face of complicated regulations.

Government assistance for company R&D in Korea has been substantial and generous, but since some issues, such as fragmentation, have been discovered, there has been pressure on the government to improve its effectiveness and impact. The Ministry of Trade, Industry, and Energy, the Ministry of SMEs and Start-ups, and the Ministry of Science and ICT are the three institutional players that are principally involved in the R&D assistance strategy for SMEs. According to Ahn, Lee, and Lee (2021), these ministries were responsible for 42.3%, 29.3%, and 8.6% of the government's total funding for R&D support aimed at SMEs in 2019. The ministries carry out a variety of R&D assistance initiatives, the majority of which concentrate on giving SMEs direct loans or subsidies for R&D (KISTEP, 2019). The policies pertaining to R&D support in Korea have been deemed excessively fragmented, despite the existence of diverse portfolios from several ministries. Over 400 distinct technology-related programs are listed on the government's web platform for SME support policies (MSS, 2021).

In addition to disjointed support systems, the following issues with R&D assistance programs for SMEs in Korea have long been recognized: 1) funding R&D for SMEs without the research capacity to use the funds wisely; 2) giving R&D subsidies to the same companies again and widely; and 3) helping companies with poor management.

Although they are still in the early stages, recent policy initiatives, such as those that link government support to private investment, emphasize collaborative R&D activities, envision long-term support throughout technology development and commercialization, and lessen the administrative burden for participating firms, are to be watched and evaluated. A novel and distinct form of governmental assistance strategy concerning public procurement to foster innovation has been advanced in Korea by means of a 2020 modification to the Public Procurement Law.

Every state agency is required to spend 1% or more of its overall procurement budget on innovative items; this aim is overseen by the Ministry of Economy and Finance. The Central Procurement Agency certifies these products for technological excellence in order to promote venture enterprises and SMEs while improving the quality of products that are procured. Support for R&D necessary to develop these items is also provided to suppliers of specific products (MOTIE, 2021).

4.4. Government-University Linkage

A distinct division of labor existed between GRIs, which conducted the majority of the research, and universities, whose main duty was teaching, throughout the early stages of industrialization and catch-up (Shin and Lee, 2015). Strong regulations that limited enrollment were in place from the 1960s to the mid-1970s, during which time institutions prioritized teaching over all other programs. Regulations were loosened and there was tremendous expansion in the late 1970s and early 1980s, most notably with the establishment of new private universities. Based on the 1989 'Basic Science Advancement Law,' research became a very essential purpose for universities during the 1990s' "first Korean academic revolution" (Kwon, 2015).

The government started making large-scale investments in university research in the late 1990s, with the Brain Korea Project, which was established in 1999, serving as a major pillar. As a result, the research university concept is very new in Korea, and the country's current research and higher education structure is different from that of many European and American nations in that GRIs were the primary research achievers at first. The swift expansion of Higher Education Institutes (HEIs) in Korea can be partly ascribed to modifications implemented during the Kim Young-sam administration in 1996, which lowered the prerequisites for founding universities (STEPI, 2021). However, the proliferation of HEIs and, consequently, departments devoted to related fields of study has raised questions regarding the effectiveness of resource allocation. In order to streamline resources, the government decided to concentrate on a small number of research-based universities. Specialized IST universities were eventually established under the MSIT, giving them greater freedom to be innovative and adaptable. This is especially true when it comes to student admissions, where they can be more creative and flexible with criteria than universities under the Ministry of Education.

Among the OECD countries, Korea's growth in university financing is one of the highest. However, regarding the size of the contribution, its contribution is smaller than the top innovators like Germany and Japan. The percentage of university R&D spending that is sponsored by the government has increased from less than 50% in 1997 to approximately 80% as of 2009 (OECD, 2022b). A total of 74,745 projects totaling approximately 350 million KRW were sponsored by ministries in 2021 (MSIT and KISTEP, 2022). However, it's unclear what the value is in terms of advancing university impact and quality or meeting strategic targets.

Research funding to higher education institutions (HEIs) in Korea in 2020 was 0.43% of GDP (OECD, 2022c), which is higher than the US at 0.39% but still below the OECD average of 0.44%. Other countries that spent more than 0.70% of GDP on HERD (Higher Education Expenditure on Research and Development) included Austria, Canada, Denmark, Finland, Norway, and Sweden. The central government provided the majority of this funding. A further quarter was provided by domestic private investment. In contrast to OECD benchmarking nations, the central government's portion of funding is disproportionately large. For instance, the federal government provided 53% of the USD 86 billion in research funding for HERD expenditures in the United States (National Science Foundation, 2021). Conversely, the French government provided 60% of the 21 billion USD spent on HERD (Minister of Higher Education, 2021).

With about 3.3 billion USD, over 60% of all research expenditures, private universities receive the greatest share of funding for research in absolute terms. Top universities receive a quarter of research funding, with IST and public universities coming in second and third.

One useful metric for differentiating between institutions that prioritize research is expenditure per researcher, which is calculated by dividing the total expenditure by the total number of researchers at the school. With a correlation value of 0.95 for graduate students and 0.7 for STEM-related courses, respectively, these indicators show a strong relationship between the university. Stated differently, a university's expenditure per researcher is higher than that of other universities if it has a higher proportion of graduate students and courses connected to STEM.

The IST universities receive the largest share of funding allocated to researchers. This is because the IST institutions needed more funding because they were initially intended to be research universities with a concentration on STEM fields. Consequently, the average salary for a researcher at an IST institution is approximately USD 390,000, which is six times more than that of a private university. This does not, however, lessen the significance of private universities in the allocation of financing. For example, compared to the top 10 flagship universities, the top ten private universities spend 70% more on each researcher. This emphasizes the role that private colleges play in R&D in Korea, especially in the PBS (project-based system; see, for example, CORE, PRIME, CK, SCK, BK21, LINC+, AGE+, etc.).

5. Weakness and Strengths of the Korean Innovation System

5.1. Global Innovation Index Analysis Perspective

The scales of the Global Innovation scores, overall as well as the sub-category scores, do not have much substantive meaning. Thus, we normalize each innovation score for Korea by either maximum or mean scores in the sample as in Table 4.2 so that we can identify Korea's relative strengths and weaknesses compared to other countries in the GII database. Table 4.2 shows that the average Korean overall GII score during the 2020-2022 period is 0.88 relative to the maximum and 1.76 relative to the mean score. This implies that the Korean innovation index is short by 12% compared to the frontier country and 76% higher compared to the average country. We may use these values as reference points to identify which innovation categories among the seven sub-categories Korea has relative strengths and relative weaknesses. We consider the innovation scores relative to the mean, rather than those relative to the maximum, as the benchmark relative scores because the outlier bias can be larger when using maximum scores than using the mean scores. The Korean innovation scores relative to the mean for the seven sub-categories vary from 1.23 for 'Institutions' to 2.19 for 'Knowledge and technology outputs.' They all exceed one. However, in order to identify dimensions of the comparative advantages or disadvantages of Korean innovation performance, we compare the relative scores of the sub-categories with the relative overall score of 1.76 rather than one.

Table 4.7 displays the ratios of the relative scores of each sub-category of innovation to the relative score of the overall GII. This identifies that among the seven categories, Institutions, Market sophistication, and Infrastructure are the three dimensions of innovation of relative weakness, while Knowledge and technology outputs, Creative outputs, Human capital and research, and Business sophistication are those of strength. In particular, Institutions, and Market sophistication are also identified as weakness areas if applying the same method using the scores relative to the maximum values rather than to the mean values. Thus, Institutions and Market sophistication seem to be the two key areas of challenge that Korea needs to improve on to become a frontier nation of innovation.

Table 4.7. Korean Comparative Advantage Ratios of Innovation Categories

Innovation Categories	Comparative Advantage Ratio
Institutions	0.70
Human capital and research	1.18
Infrastructure	0.81
Market sophistication	0.76
Business sophistication	1.11
Knowledge and technology outputs	1.24
Creative Outputs	1.21

Observation of the changing patterns of the rankings of the seven innovation pillars over time during the 2020-2023 period reinforces the above findings. Table 4.8 reports the rankings of the overall and seven categories (pillars) of the GII sample countries from the Global Innovation Index Reports for the 2020-2023 period. The year 2020 was when Korea first entered into the top ten groups and maintained its top ten group position until 2023. The stable top performance for the Human capital and research pillar of innovation and the rising rankings from 14th to 5th for the Creative outputs are noticeable. However, the low rankings for the Institutions and Market sophistication pillars are equally noticeable. Furthermore, for those two categories of innovation pillars, rankings have declined from 29th to 32nd for Institutions and 11th to 23rd for Market sophistication. The year 2023 neighborhood countries in terms of Institution rankings are Belgium (30th), Uruguay (31st), Rwanda (33rd), Malta (34th), and Portugal (35th). The Institution rankings for the other countries in this study are 16th (US), 21st (Japan), and 43rd (China) out of 132 sample countries. The year 2023 neighborhood countries in terms of Market sophistication rankings are Germany (21st), Thailand (22nd), Mauritius (24th), UAE (25th), and Belgium (26th). The Institution rankings for the other countries in this study are 1st (US), 8th (Japan), and 13th (China) out of 132 sample countries.

Table 4.8. Changes of Rankings of the Categories of Innovation Pillars of Korea

Innovation Categories	2020	2021	2022	2023
Overall	10	5	6	10
Institutions	29	28	31	32
Human capital and research	1	1	1	1
Infrastructure	14	12	13	11
Market sophistication	11	18	21	23
Business sophistication	7	7	9	9
Knowledge and technology outputs	11	8	10	11
Creative Outputs	14	8	4	5

There are 80 measured indicators behind the rankings of the innovation pillars.[3] The

3 See Appendix III of the Global Innovation Index 2023 for the detailed definitions and data sources of the underlying 80 indicators.

Global Innovation Index 2023 illustrates the scores and rankings of these 80 indicators and identifies the areas of the strength and weakness of innovation for each sample country. There are two ways of assigning the areas of strength and weakness for each of the 80 indicators. First, when the percentile rank of the score of an indicator is greater than the top 10 percentile rank among the 80 indicators for a given economy, "strength" is assigned to that particular indicator. Similarly, "weakness" is assigned if the percentile rank of the score of an indicator is lower than the bottom 10 percentile rank among the 80 indicators. This way, the "strength" vs. "weak" areas of indicators are those of "within-country" relative strength and weakness. Second, "income-group strength" is assigned to a particular indicator for a given economy, when the score of the indicator exceeds the score of mean plus one standard deviation among the same income group countries. Similarly, "income-group weakness" is assigned to a particular indicator for a given economy, when the score of the indicator is below the score of mean minus one standard deviation among the same income group countries according to the World Bank income group classification.[4] Thus, the "income-group strength and weakness" areas indicate the "between-country" relative strength and weakness, controlling for the income level measured by the real GDP per capita in PPP terms. Therefore, the measured classification of the strengths and weaknesses of the two kinds of concepts may diverge from each other.

Table 4.9 lists the identified areas of strength and weakness of innovation for the Republic of Korea, as reported by the Global Innovation Index 2023. We report the strength-weakness areas according to two methods, (i) the within-country strength-weakness assignment marked by "w", and (ii) the between-country strength-weakness marked by "b".

For the two pillars of Institutions and Market sophistication, the comparative advantage ratios of which were below one, there are no strength areas, while the strength and weakness areas are mixed for other pillars. For the Institutions pillar, the "Cost of redundancy dismissal" and the "Policies for doing business" indicators are the weakness areas for Korea. This appears to be puzzling. The "Cost of redundancy dismissal" indicator tries to capture how much the workers are protected in case of dismissal from employment by measuring

4 The World Bank income group classification sorts out the countries into four income groups of High, Upper Middle, Lower Middle, and Low using the real GDP per capita in PPP terms.

the sum of the 'notice period' and 'severance pay' for redundancy dismissal (salary in weeks, averages for workers with one, five and 10 years of tenure, with a minimum threshold of eight weeks). Korea is ranked 111th, close to the bottom 15 percentile group and even lower than most of developing countries. That is, firing redundant workers is very difficult in Korea. The GII considers this labor market rigidity can be a hurdle to flexible adjustment of innovation process at times of uncertain environments. It is worth mentioning that this dimension of labor market flexibility has an orthogonal component from worker protection, which is more related to the institutional aspects of safety net provision by the government. Though not included in the GII indicators because it is about innovation capacity rather than social welfare, the lack of the safety net provision by the public sector seems to be a root cause of the observed rigidity of the labor market in the private sector.

The "Policies for doing business" indicator is the outcome of the Executive Opinion Survey, answering the question "In your country, to what extent does the government ensure a stable policy environment for doing business?" Korean business executives are fairly negative to this question. That is, the business executives in Korea do not expect the government to take an active role in stabilizing the environment for doing business. This distrust of government can be an important hurdle for the business to take serious risks which are involved in pursuing new innovations.

Table 4.9. Strength and Weakness Areas of Innovation of Korea

	A. Strength	B. Weakness
1. Institutions	None	- Cost of redundancy dismissal (27.4: 111th) [wb] - Policies for doing business (52: 58th) [b]
2. Human capital and research	- Government funding/pupil, secondary, % GDP/cap (36.3: 3rd) [wb] - Tertiary enrolment, % gross (102.5: 4th) [wb] - Researchers, FTE/mn pop (9,097.1: 2nd) [wb] - Gross expenditure on R&D, % GDP (4.9: 2nd) [wb] - Graduates in science and engineering, % (30.2: 18th) [b]	- Tertiary inbound mobility, % (3.7: 58th) [wb]

	A. Strength	B. Weakness
3. Infrastructure	- ICT use (98.4: 4th) [wb] - Government's online service (98.1: 3rd) [wb] - Gross capital formation, % GDP (32.1: 18th) [b]	- GDP/unit of energy use (7.7: 90th) [w] - Environmental performance (47.5: 49th) [b]
4. Market sophistication	None	- Venture capital (VC) investors, deals/bn PPP$ GDP (0.1: 34th) [b] - VC recipients, deals/bn PPP$ GDP (0.0: 63rd) [wb] - VC received, value, % GDP (0.0: 41st) [b] - Applied tariff rate, weighted avg., % (5.5: 94th) [wb]
5. Business sophistication	- GERD performed by business, % GDP (3.9: 2nd) [wb] - GERD financed by business, % (76.4: 4th) [b] - Patent families/bn PPP$ GDP (12.5: 1st) [wb] - Research talent, % in businesses (82.9: 1st) [wb]	- Knowledge-intensive employment, % (39.6: 31st) [b] - GERD financed by abroad, % GDP (0.0: 69th) [wb] - ICT services imports, % total trade (1.2: 74th) [wb] - FDI net inflows, % GDP (0.7: 106th) [w] - Joint venture/strategic alliance deals/bn PPP$ GDP (0.0: 32nd) [b]
6. Knowledge and technology outputs	- Patents by origin/bn PPP$ GDP (74.0: 1st) [wb] - PCT patents by origin/bn PPP$ GDP (8.0: 1st) [wb] - Production and export complexity (93.4: 4th) [b] - High-tech exports, % total trade (27.9: 6th) [b]	- Software spending, % GDP (0.2: 65th) [wb] - ICT services exports, % total trade (1.6: 68th) [w]
7. Creative Outputs	- Industrial designs by origin/bn PPP$ GDP (24.4: 3rd) [wb] - Trademarks by origin/bn PPP$ GDP (119.0: 7th) [b] - Creative goods exports, % total trade (5.0: 12th) [b]	- Generic top-level domains (TLDs)/th pop. 15–69 (9.5: 43rd) [B] - Country-code TLDs/th pop. 15–69 (8.0: 44th) [b]

Note) The first number in parenthesis of each indicator is the score and the second one is the ranking among 132 countries. The within-country strength-weakness indicator is superscripted by "w" and the between-country strength-weakness indicator is superscripted by "b", next to the parenthesis.

Table 4.9 suggests that the main reason for Korea's weakness in Market sophistication is related to the lack of venture capital activities. The scores of all three indicators regarding venture capital activities, VC invested deals, VC received deals, and VC received values relative to GDP, are relatively low among the high-income countries, though not among all countries. The "Joint venture/strategic alliance deals (normalized by PPP adjusted GDP in billion dollars)" indicator, which is not in the Market sophistication pillar but in the Business sophistication pillar, also shows a between-country weakness (ranked at 32nd) among the high-income countries.

This lack of venture capital activities, an important channel of entrepreneurial risk-taking, either at the macro level or at the business level, is likely to be related to the above-mentioned weak institutional factors of doing business. That is, the two relatively weak pillars of Korea's innovation are in part rooted in the labor market rigidity and the pessimistic expectation of the business sector for the stability of government policies for doing business.

Korea is ranked 16th for the sub-category of "trade, diversification, and market scale" so its position in the global market is favorable. However, the weighted average of the applied tariff rate is 5.5% for Korea in 2020. The world average of this indicator is 2.6% in 2017. The same indicator values are 1.5% for the USA, Germany, and France, 2.2% for Japan, 2.5% for China, 1.3% for Viet Nam 0.1% for Singapore so that we may think the Korean tariff rate is fairly high compared to other countries. However, this in fact is misleading. This indicator is about the "applied" tariff rate. For most of the products, Korean tariff rates are zero. For example, 98% of the US products imported to Korea were duty-free in 2020. In contrast, the Chinese share of duty-free products from the US is only 31% in 2021. This illustrates a potential problem of measuring the innovation score for the sub-category of "trade, diversification, and market scale" in the GII measurement system, which discounts the overall GII score in the case of Korea.

However, it is worth noticing that ICT 'services trade is identified as a weakness area for Korean innovation according to either within-country or between-country relative performance methods. The ICT services imports share of total trade (an indicator of the Business sophistication pillar) is only 1.2% (74th) and the ICT services exports share of total trade (an indicator of the Knowledge and technology outputs pillar) is 1.6% (68th). Although Korea is a leading country in terms of using ICT goods and services and producing ICT manufactured goods, Korea is lagging behind in trading ICT services.

This is identified as a weakness of Korea's innovation. The development of ICT services is based mainly on ideas, which is a crucial aspect of innovation. Thus, this weakness can be an important challenge for Korea if the trade of ICT services indeed is an important channel of idea creation and sharing.

5.2. Fundamentals Perspective

5.2.1. Weakness

The above analysis of the weaknesses and strengths of the Korean national innovation system is based on very detailed indicators in the GII system. Such an approach has the benefit of quantitatively evaluating the NIS in line with specific variables in concrete contexts. However, the list of selected indicators cannot capture all essential features of the NIS for every country. Some opinion indicators can be too subjective to interpret the response scores let alone the typical index problems such as cross-country comparability and aggregation issues. Thus, here we provide a qualitative assessment of Korean NIS from the perspective of the fundamentals of Korean society and economy. It turns out that this assessment is consistent with the quantitative findings in the previous sub-section.

There are many challenges for the Korean NIS. To name the most critical one, however, it can be summarized by one factor, the unfavorable institutional and policy environments for risk-taking by entrepreneurs. Here, it is important to clarify that entrepreneurs do not mean capitalists or corporate owners. Entrepreneurs are people or organizations, small or large, who are willing to implement innovative ideas. The single core metric in evaluating NIS should be whether the built-in socio-economic system can successfully *protect as well as promote* entrepreneurial activities, the essential components of which are risk-taking and risk management.

The first fundamental factor in relation to the weakness of Korean NIS is that institutional and policy environments are not so favorable for risk-taking. There exists a long tradition of policy loans for targeted industries or SMEs. The key problem of those policy loans lies not in the fact that they are concentrated on selected industries or companies but in that they deprive the incentives for future innovation. Furthermore, renewal of those policy loans is based on the past records of receiving policy loans and business history rather than the proposal of innovative ideas. Thus, they in fact are a critical barrier to the entry of brand-new firms with great ideas because they do not have past records, while the existing SMEs are losing the incentives to further innovate. In consequence, the policy loans tend to protect the incumbent SMEs with few new ideas and to demote the innovations of new firms, which is ironic. Financing schemes for startups and scaleups are less developed. Legal protection for personal and corporate bankruptcy is considered weak and costly. In sum, Korean financing schemes are not favorable for entrepreneurial risk-taking.

Second, another fundamental barrier is the rigidity of the Korean labor market in both hiring and firing. It is very difficult to fire unproductive workers in Korea. Unconditional job security for unproductive workers is a burden not only for employers but also for other workers. A fundamental problem in the Korean labor market is that such burdens are borne mostly by employers who are supposed to have room for discretion in hiring. The protection of workers from the potential job insecurity is indeed important. However, it is the government that should take the main responsibility for job stability. Instead, such responsibility is shifted to firms, and this rigid labor market environment creates a substantial fixed cost in managerial decisions, in which in turn is a critical obstacle to risk-taking for innovations toward unknown areas.

The observed Korea's low rankings of the GII indicators like venture capital activities, GERD financed abroad, and the net FDI inflows in the previous subsection can be just symptoms of these two fundamental features of institutions and markets. Thus, the scores of the "institution" and "market sophistication" innovation pillars are low pulling down Korea's overall GII index, while "human capital and research," "business sophistication," and "creative output" innovation pillars are ranked above the top ten.

Third, Korea's lack of accumulated experience of software innovation and ICT service innovation is also an important weakness in particular from the global competitiveness perspective. Korea has been good at manufacturing and making gradual improvements but has little experience with disruptive innovations at the global frontier. Resolving this problem requires more fundamental reforms for the education system and corporate culture. This will be the core of Korea's next-round transformation.

Fourth, current Korean R&D spending is allocated to 'development' (70%) rather than 'research' (30%). Even among the research, the portion of applied research is 20% and only 10% of R&D is spent on basic research. That is, Korean R&D is too oriented to practical purposes. This (mis)allocation of R&D may be the root cause of the weak software innovation and the lack of disruptive innovations at the global frontier. Such an investment pattern seems to reflect the short-sightedness of both private and public sectors in envisioning an innovative Korea. Korean NIS should correct this myopic strategy and incentives in order to sustain the innovations for long.

Fifth, current STI policy governance is too complicated and ineffective, although it appears to be designed in a sophisticated way. Too many ministries need to be coordinated without having a common and simple core principle to guide the coordination. Furthermore, long-term visions are missing in the current STI five-year strategic framework on which the actual entrepreneurs can hinge in forming their own innovation plans and investments.

Sixth, the Korean economy is very open to the outside for both trade and investment and is highly integrated into global value chains. This in fact is a crucial strength of Korea. However, the consequential heavy reliance on the external sector, hence the global risk exposure can be a limitation factor in widening the scope of risk-taking. Therefore, balancing the benefits and costs of global openness is an important challenge for Korean NIS. From this perspective, the appropriate formation of an innovation alliance is critical for Korea.

Seventh, exceptionally low fertility, the recent TFR around 0.7, and the expected continuous decrease in population can be potentially the most serious long-term danger for innovations in Korea. Innovations occur from new ideas and new ideas are born from people. A declining population implies a shrinking of the pool of new ideas. Of course, turning the potential new ideas into innovation requires both capability and incentive systems for implementing innovations and population is not everything. However, the population still matters in particular when other countries catch up with the capability and incentive system for innovation.

5.2.2. Strength

Despite the above weaknesses of the innovation fundamentals, Korean NIS has also strength in critical dimensions. There are reasons why Korea has been in the top ten innovation countries since 2020. The GII analysis suggests that the three innovation pillars of "human capital and research," "business sophistication," and "creative output" are the main strength areas of Korean NIS.

The first thing to notice regarding the three areas of strength is that they are all about the private sector. That is, despite the weakness of the institutional and market factors, the innovation pillars which are mainly driven by the private sector are strong in Korea. It is interesting to notice that Korea's "business sophistication" is strong although the "market sophistication" is weak. This is possible because of Korea's strong adaptability to bad environments and high resilience to environmental changes and external shocks which have been repeatedly observed during the last 6p-6d growth era.

Second, the most outstanding area among the three pillars of strength is "human capital and research" which has been number one throughout since 2020. The college advancement rate of around 75% is simply an outlier achievement of higher education by any standard. The abundance of college graduates and researchers in STEM is also exceptional. This is a promising thing to pay attention to because it is about Korean people and innovation ultimately comes from people. To be specific, the "human capital and research" pillar is about the capability of people, to create and implement innovations. Institutions are hard to change but once there occurs a momentum for reform, it can happen shortly. However, building the capability and quality of workers takes a long time. In other words, Korea has the strength in the innovation pillar which is the most fundamental and the most difficult to build. Embedded with the reservoir of a high-quality workforce, Korea is a quick adopter of emerging new technologies. For example, the Korean density of robot workers (number of robots installed per 10,000 employees in the manufacturing industry) is the highest at 1,000 in 2021, followed by Japan at 399 and Germany at 397. This kind of innovation adaptability because of the high level of human capital can also be an important leverage for Korea in forming a global innovation alliance.

Third, the social connection of Korean people is very deep and fast. This is illustrated by various measurable indicators such as the high rate of internet use and the top rate of internet speed in the world. Though not captured by the previous indicators, the frequency and speed of news and information spread are also very high among Korean people. That is, Korean people are very active in idea sharing. This can be a crucial strength of Korean NIS because the room for innovation promotion starts from 'idea sharing' in which Koreans are exceptionally active. Furthermore, such idea-sharing and interactive communications are mostly done on many ICT platforms. This implies that the data pool is very large in Korea which can be utilized in developing future technologies, for example, AI.

Fourth, Korea has a traditional strength in manufacturing in terms of both mass production capacity and precision. This advantage can play an important role in directly "implementing" or "materializing" innovative ideas from inside and outside of Korea rather than relying on other countries. This also can be again an important leverage for Korea to form a global innovation alliance.

6. Strategy to Improve on the Korean Innovation System

The most critical message that Korea's last six-decade development experience delivered to the world is that such a dramatic transformation from one of the most devasted poor countries to one of the top-tier global economic powers is *possible*. We showed that the facilitation of active investment in various dimensions during the first three-decade period triggered its take-off (Korea's First Fundamental Transformation) and the switch into innovation-driven productivity growth (Korea's Second Fundamental Transformation) during the following three-decade period was the secret behind maintaining the rapid growth without getting swamped by the middle-income trap. According to the numbers such as the Global Innovation Index, Korea is considered to belong to the top ten group of innovative countries. We found, however, that there are several weaknesses and challenges that Korea should resolve. In particular, Korea recently entered into the low-growth stage and Korea needs a Third Fundamental Transformation, which requires essential reforms in the Korean national innovation system.

Our analysis suggests that many critical barriers to promoting effective innovations in Korea boil down to the lack of institutional, either legal or financial, environments that promote and also protect the risk-taking of entrepreneurs. Such deficiency spreads out in diverse manifolds of society. A rigid labor market, ineffective SME subsidy policies, sluggish start-ups and scale-ups, and lack of venture financing are just manifestations of such institutional deficiency. Weakness in software innovation is also one of the consequences of these manifestations. Therefore, the most fundamental strategy to improve Korean NIS is to renew the institutional environments which will effectively promote and protect the risk-taking of entrepreneurs. This requires a paradigm shift in perceiving the economy in relation to science, technology, and innovation. Otherwise, the Third Fundamental Transformation won't come in Korea.

We also argued that there exists a big hope for Korea to make such changes happen because of the accumulated human capital stock with high-quality workers and researchers, a strong tradition of making tangible things in manufacturing, and finally the active mindset of the private sector agents of the Korean economy.

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Chapter 5

China

KIM Yong June, Robert D. Atkinson

1. Overview of China's National Innovation System

1.1. History and Evolution

The evolution of China's National Innovation System (NIS) underscores a concerted effort to close the technological and economic gap with the West. This endeavor began in the 1940s with President Chiang Kai-Shek's push for technological modernization but saw a period of stagnation following the Communist Party's rise to power in 1949 under Mao Tse Tung.

The landscape shifted significantly in the early 1980s with Deng Xiaoping's reform policies, which marked the beginning of China's openness to international investment and economic development through foreign direct investment (FDI). The government implemented a variety of incentives to attract FDI, including tax breaks, provision of free land, minimal regulation, and currency manipulation, all aimed at encouraging technology transfer to domestic enterprises from multinational corporations.

By 2006, China's strategy pivoted towards enhancing the competitiveness of domestic firms, usually at the expense of foreign entities, under the "China Inc." model. This was a shift from attracting commodity-based production to promoting indigenous innovation (自主创新), with a focus on the development of Chinese-owned companies. This shift was highlighted in the "Guidelines for the Implementation of the National Medium- and Long-term Program for Science and Technology Development (2006-2020)," which advocated for a comprehensive strategy to boost competitiveness through innovation, emphasizing the need for self-sufficiency in critical technological areas.

The Medium- and Long-term Program for Science and Technology Development (2006-2020), or MLP(国家中长期科学和技术发展规划), described indigenous innovation as enhancing original innovation, integrated with collaborative and renewed innovation, leveraging imported technologies. This strategy aimed to address several critical challenges:

1. China's limited proficiency in entrepreneurial innovation
2. Deficient technological skills in critical economic and societal sectors like resource management and healthcare
3. Heavy dependence on overseas technology for financial, civilian, and defense sectors
4. The departure of China's leading experts in science and engineering
5. The imposition of royalties and licensing fees on Chinese manufacturers by international corporations
6. Recognition that relying solely on foreign tech doesn't guarantee sustained economic growth

To overcome these obstacles and drive China towards greater technological self-reliance and innovation, the MLP identified key economic sectors, technologies, and large-scale projects for government support. This included targeting sectors like energy, water resources, environmental protection, agriculture, manufacturing, transportation, information services, population and health, urban development, and public and national security. Highlighted technologies encompassed biotechnology, information technology, advanced materials, advanced manufacturing, energy technology, marine, laser, and space technologies, with state-funded megaprojects focusing on protein science, nanotechnology, quantum physics, and developmental and reproductive science.

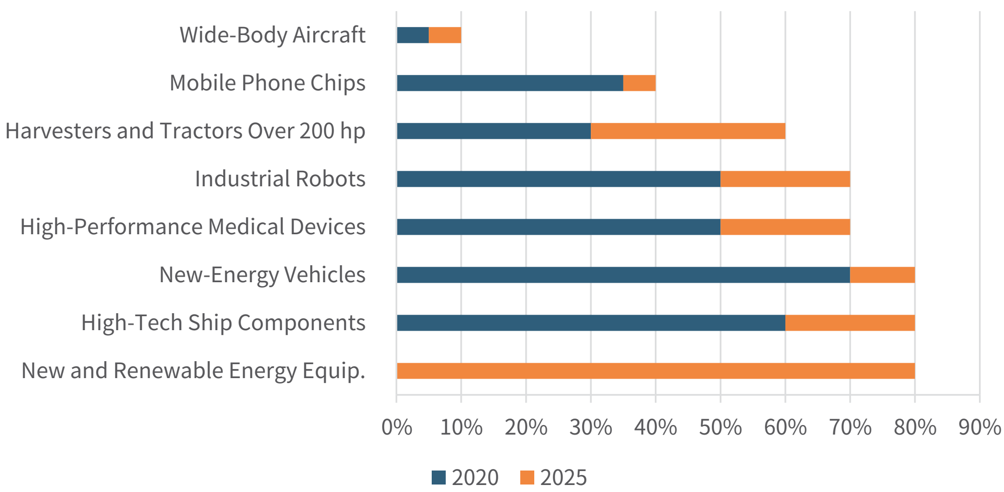
Since the introduction of the MLP, China has pursued a development model that supports domestic companies in moving up the value chain and expanding their global market share. This includes very large government production subsidies, appropriation of foreign expertise, and mandating technology transfer as a condition for market entry, as well as export subsidies and biased government procurement practices. The overarching goal is to enable

Chinese companies to replace foreign tech entities both domestically and internationally.

The introduction of the Thousand Talents Program(千人计划)in 2008 and the Strategic Emerging Industries(战略性新兴产业)strategy further refined China's efforts towards innovation and talent attraction. Subsequent policies, including the Made in China 2025(中国制造2025)Strategy and various five-year plans focusing on science, technology, and cybersecurity, have been aimed at strengthening local manufacturing, limiting competition from foreign enterprises in emerging ICT sectors, and establishing China as a cyber superpower.

The Made in China 2025 strategy, in particular, has been critiqued for altering domestic markets to favor Chinese enterprises at the expense of foreign competitors. This strategic direction not only aims to innovate but also to dominate high-tech industries, marking a significant shift in China's innovation policy towards market outcomes and the enhancement of manufacturing processes.

Figure 5.1. **Domestic Market Share Targets under Made in China 2025**



Similar to the Medium- and Long-term Program for Science and Technology Development (MLP), the Made in China 2025 initiative (MIC) delineates priority industries for development, establishing specific objectives for these sectors by 2020 and 2025. The targeted areas encompass advanced information technology, robotics, aerospace equipment, maritime technology, modern rail systems, green vehicles, energy technology, agricultural machinery, innovative materials, biotechnology, and advanced medical products. MIC sets ambitious goals, including achieving a local content rate of 40% by 2020 and 70% by 2025 in critical components, establishing up to 40 innovation centers by 2025, elevating corporate research and development expenditure to 1.68%, securing a 7.5% annual enhancement in labor productivity through 2020, and attaining a 35% decrease in energy and water consumption per unit of output by 2025.

MIC signifies a pivotal shift in China's innovation strategy, prioritizing market-driven outcomes and the commercial application of novel technologies beyond mere scholarly or patent achievements. This reflects a comprehensive perception of innovation as a process that encompasses not only invention but also widespread market adoption.

Analyzing China's innovation ecosystem necessitates recognition of its unique governance structure under a communist regime paired with a distinctive economic model. China's mixed economy, heavily influenced by the Communist Party, merges Marxist-Leninist principles with a socialist market economy framework. This model, contrasting with Western capitalism, is characterized by the significant presence of state-owned enterprises and the Communist Party's extensive involvement in economic planning and regulation across all sectors.

In the mid-2000s, acknowledging its technological lag behind global innovation leaders, China formulated a strategy centered on acquiring and integrating external technology and expertise to lay the foundation for domestic innovation.

At the heart of China's innovation strategy is the acquisition of foreign technological knowledge, with Chinese policymakers recognizing that attaining their ambitious goals for indigenous innovation necessitates rapid assimilation of international expertise.

To this end, China has adopted various tactics, including mandatory technology transfers for market access, unauthorized appropriation of foreign intellectual property, legal pressures to compel foreign companies into licensing their technology at reduced rates, and state-backed acquisitions of foreign enterprises.

Technology transfer, contingent upon market access, emerges as a key strategy for acquiring foreign technology, impacting a wide array of industries such as aviation, automotive, chemicals, renewable energy, and high-speed rail. Furthermore, intellectual property theft poses a significant challenge for multinational companies in China, leading to substantial economic losses due to IP rights violations.

Additionally, Chinese firms have sought to acquire technology by purchasing foreign tech companies, though such efforts face increasing scrutiny and resistance from foreign governments. This strategic emphasis on obtaining cutting-edge technology underpins the Made in China 2025 initiative, envisioned as an all-encompassing strategy to pursue technology through investment.

The Chinese government actively promotes investment in leading foreign technology firms to secure advanced technologies and facilitate significant technology transfers. This approach of state-driven foreign direct investment (FDI) in high-tech sectors represents a recent development, with its full impact and precise outcomes yet to be fully determined. Nonetheless, it's conceivable that China's extensive technology acquisitions could challenge the technological supremacy of industrialized nations in certain fields.

Chinese technology-focused FDI acquisitions are integral to a broader strategy aiming at global knowledge acquisition to surpass current technological leaders, including the United States. This strategy entails selectively targeting strategic assets from "hidden champions" to absorb knowledge and penetrate high-end markets. Research on Chinese acquisitions in Germany indicates that these moves are driven primarily by the desire to access the inherent knowledge of target companies, such as engineering skills, technological assets, brand reputation, customer relationships, and global distribution networks, diverging from typical FDI goals focused on integration, synergies, and efficiencies.

In industries like biopharmaceuticals, policies are designed to facilitate Chinese companies' access to U.S. technology. For example, the relatively short six-year data exclusivity term in China, coupled with a broad definition of "new chemical entity," pressures U.S. firms to share crucial data with Chinese generic manufacturers. Moreover, China requires drugs to be locally tested through clinical trials for market approval, even if already approved in the U.S., which delays market entry and shortens the duration of patent-protected sales. Unlike in the U.S. and Europe, China does not offer marketing exclusivity to compensate for these delays and can issue compulsory licenses for drug patents. Foreign biopharmaceutical companies are also pressured into joint ventures to have their drugs included more readily in government reimbursement lists.

Additionally, China prioritizes establishing indigenous technology standards for ICT products as a key component of its industrial and economic growth strategy. Despite existing international standards, China aims to develop unique national standards for various high-tech and ICT products, including mobile services, wireless networks, encryption technologies, and the Internet of Things.

Chinese tech companies benefit from the ability to absorb losses in international markets due to China's vast domestic market, allowing them to offset overseas losses with domestic sales. The strategy of "exchanging market for technology," which requires foreign companies to form joint ventures with Chinese firms for market access, combined with extensive government subsidies to domestic industry leaders, underpins China's strategy for global competitiveness in advanced industries.

Recognizing the complexity of producing advanced technology, China employs a strategy of acquiring foreign knowledge and capabilities, including intellectual property theft, enforced technology transfer, and state-backed investments in foreign firms. Once acquired, China supports its domestic champions with subsidies and market protection to enhance their development and international competitiveness.

Recent U.S. policies have prompted China to emphasize technological self-sufficiency as a national priority. This reflects governmental support for science and technology policies focusing on original innovation, integrated innovation, and re-innovation through the "IDAR" model.

Also, it is important to note that like the Asian tigers at similar levels of development, China's national innovation systems is almost exclusively focused on strengthening exports and reducing imports, and not on innovation in the domestic-serving industries, even though the latter is critical to boosting productivity and living standards.

The primary shortcomings of China's S&T strategy include potential misallocation of resources, redundant investments in sectors like semiconductors and life sciences, and the production of low-quality publications and patents. Many of these technologies may end up in state-owned or supported enterprises lacking market competitiveness. Moreover, China's aggressive approach to developing S&T industries could provoke a backlash from affected countries, potentially hindering China's efforts to expand its global market presence.

1.2. Current Perspectives

Initiation of Indigenous Innovation (2006–2010)

The journey towards modernizing China's innovation landscape commenced with the "indigenous innovation" drive, inaugurated by the Medium- to Long-Term Program for Science and Technology Development in 2006. This initiative sought to boost homegrown innovation by leveraging, assimilating, and re-innovating upon imported technologies. It aimed to tackle several pressing issues: bolstering China's commercial innovation, enhancing technological capabilities in critical sectors, reducing dependency on foreign technology, stemming the talent drain, and addressing the costly appropriation of foreign technology.

Transition to Made in China 2025

The announcement of the Made in China 2025 (MIC) initiative marked a significant milestone, signifying a shift towards outcomes driven by market forces, with clear, quantifiable objectives and an enhanced role for market mechanisms. MIC's strategy was to propel innovation-led "smart" manufacturing, cultivate and attract talent, secure a dominant position in the global value chain's high-value segments, and fortify intellectual property rights and protections.

Policy Shifts and Characteristics

Under MIC, China's innovation policies matured from a narrow focus on indigenous innovation to embrace a broader, market-oriented approach, mirroring ambitions akin to Germany's "Industry 4.0". This new phase outlined specific targets for domestic content requirements, the establishment of innovation centers, corporate R&D intensity, improvements in labor productivity, and reductions in energy and resource consumption.

Impacts and Perceptions

Despite facing criticism for its protectionist and mercantilist tendencies under the guise of promoting innovation, China has made substantial strides in various sectors, showcasing its prowess in efficiency-driven and customer-focused innovations and making advances in engineering and science-based innovations. Noteworthy achievements include breakthroughs in electric vehicles, high-speed rail technology, space exploration, and the development of digital infrastructure.

Challenges and Prospective Directions

While China's progress is undeniable, challenges persist, particularly concerning the efficiency of state involvement, the need for a balance between scalability and efficiency, and potential barriers to productivity growth. Nevertheless, it's crucial to recognize China's advancements and their implications for the global innovation landscape, underscoring the need for careful consideration of China's role in shaping future technological trends and competitiveness on the world stage.

This study embarks on a comprehensive examination of the recent trends, alongside an analysis of the Inputs, Outputs, and Outcomes associated with China's National Innovation System (NIS). It meticulously differentiates between the Costs, Outcomes, and Outputs of the NIS. Herein, NIS Outputs are delineated as the conventional tangible and intangible results emanating from NIS inputs, whereas NIS Outcomes encapsulate the advanced ramifications of NIS Inputs, including their influence on domestic and global market shares.

To scrutinize the reactive performances of China NIS's Inputs & Outputs, the investigation draws upon data from the Global Innovation Index (GII) for the years 2018 through 2023. Additionally, to delve into NIS Outcomes, this study analyzes the Hamilton Index from 1995 to 2020.

Through this analytical lens, the study aims to unravel the complexities of China's NIS, offering insights into the strategic impacts of innovation inputs on market dynamics and international competitiveness.

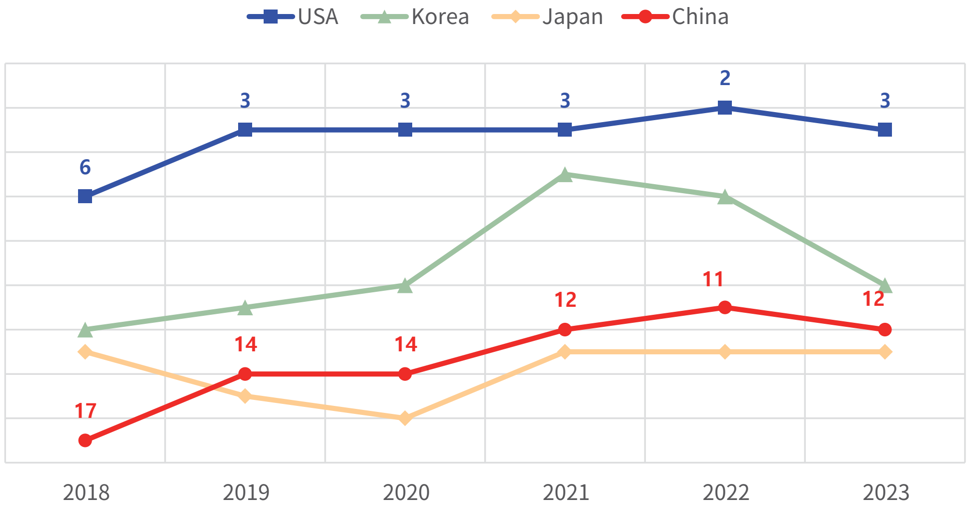
2. Analysis of China's NIS Inputs & Outputs by GI Indexes

2.1. Overview of Global Innovation Index (GII)

This analysis leverages the Global Innovation Index (GII) for the years 2018-2023, as reported annually by the World Intellectual Property Organization (WIPO). In section 3, Outcomes are measured using the Hamilton Indexes from 2021 to 2023, providing an enhanced perspective on innovation performance. The GII is a multifaceted benchmark that assesses the innovation ecosystem of countries by aggregating a wealth of data pertaining to their national innovation capabilities. It bifurcates into two principal domains—'Inputs' and 'Outputs,'—which together encapsulate various pillars that are instrumental in gauging the efficiency and output of innovation systems.

Through this graph, we observe the innovation trajectory of four leading economies: the United States, South Korea, Japan, and China. The rankings are indicative of the nations' respective positions in the global innovation landscape, revealing insights into their progress and competitive dynamics over the six years.

Figure 5.2. **GII Rankings (2018-2023): USA, Korea, Japan, China**



As depicted, the United States has maintained a consistent rank, indicating stability in its innovation ecosystem. South Korea and Japan have shown fluctuations in their rankings, suggesting a dynamic shift in their innovation outputs and strategies. China's marked ascent in the GII rankings is particularly noteworthy, highlighting significant growth in its innovation capabilities and strategic investments in intellectual property and technology.

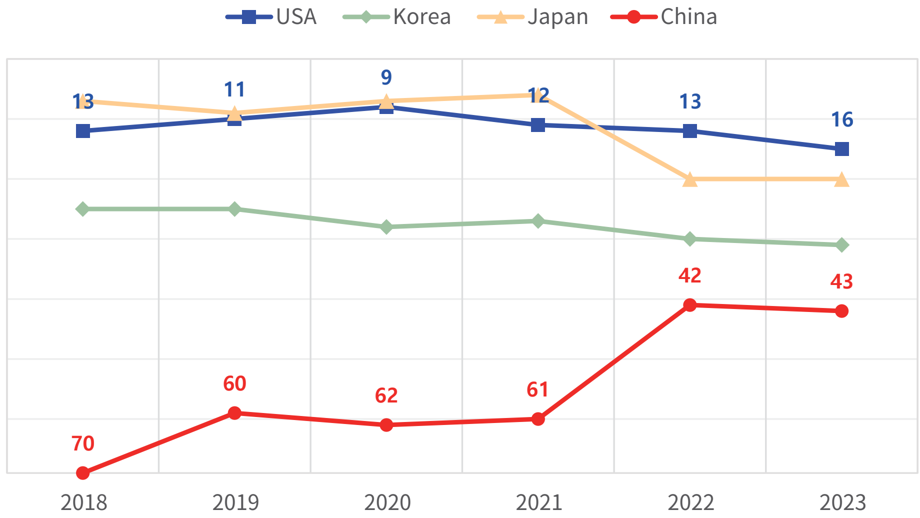
Analyzing the GII trends for China, this study examines the sub-factors of Innovation Inputs and Outputs between 2018 and 2023 to discern detailed changes for future forecasting.

2.2. Innovation inputs

2.2.1 Institutions

According to the GII by WIPO, Innovation Inputs comprise five sub-factors: Institutions, Human Capital & Research, Infrastructure, Market Sophistication, and Business Sophistication.

Figure 5.3. **Institutions Rankings (2018-2023): USA, Korea, Japan, China**



Institutions Ranking of China, 2018-2023

The depicted data tracks the evolution of institutional rankings in the Global Innovation Index (GII) for the United States, South Korea, Japan, and China from 2018 to 2023. It examines the progress within each country's institutional framework concerning innovation.

China demonstrates a significant climb in its overall score from 59.4 to 60.2, ascending from 70th to 43rd position. This rise underscores substantial improvements in China's political environment, which experienced a score increase from 53.6 to 56.4, and its government effectiveness, escalating from 54.1 to 60.0. These advancements signify China's commitment to reinforcing its institutional infrastructure to bolster innovation.

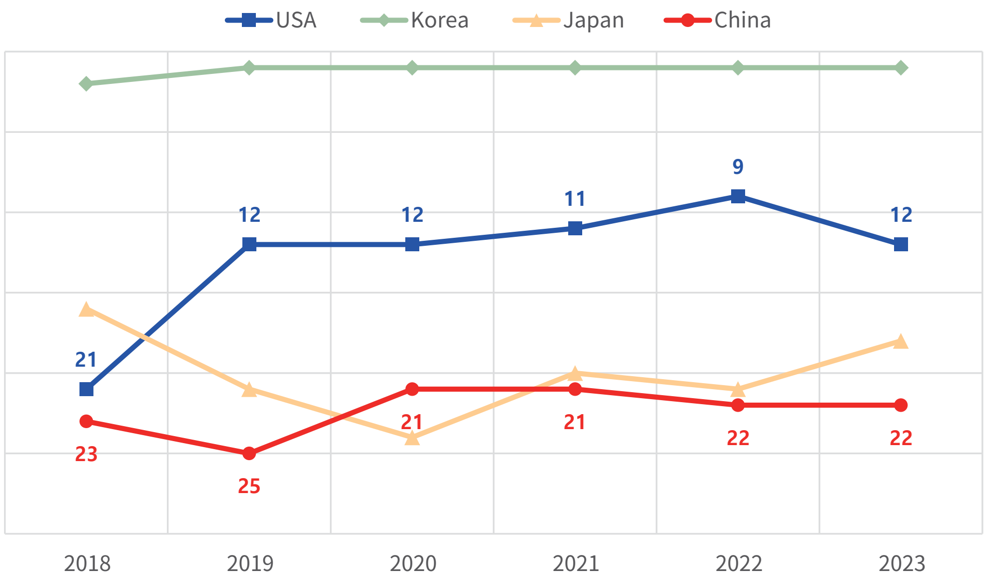
Despite a dip in the regulatory environment score from 54.0 to 49.5, China's rank in this domain remained at 100th place, suggesting the decrease did not drastically alter its comparative global standing.

In stark contrast, China's business environment saw a considerable score increase from 70.6 to 74.9, indicating efforts to create a more advantageous and competitive setting for businesses, essential for fostering innovation.

The data for the other countries show a mix of stability and change. The United States and Japan demonstrate variability in their institutional rankings, whereas South Korea maintains a relatively steady position throughout the period in question.

2.2.2 China's Human Capital and Research

Figure 5.4. Human Capital & Research Rankings (2018-2023): USA, Korea, Japan, China



Human Capital and Research Ranking of China, 2018-2023

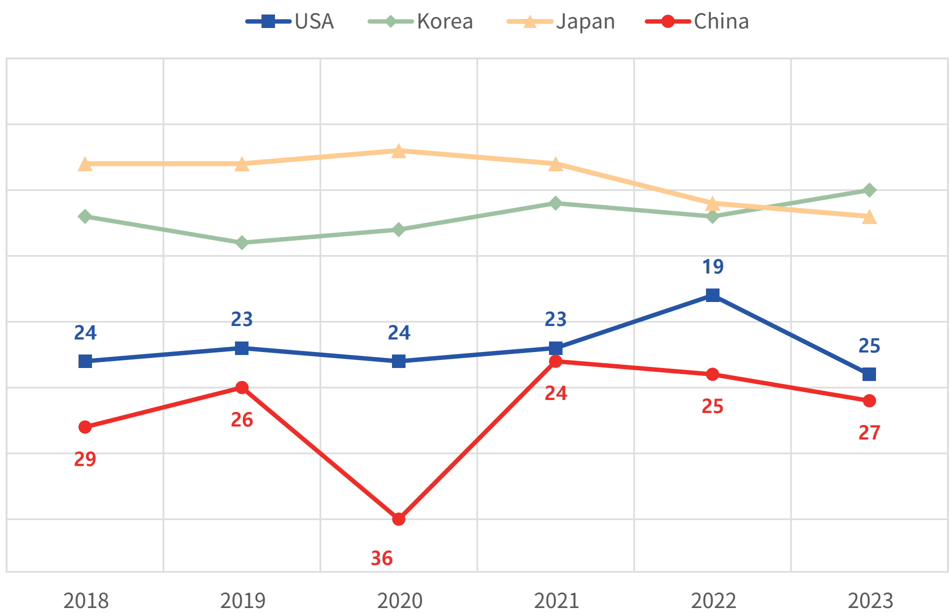
Over the six years, China's overall score for Human Capital and Research on the GII experienced a modest increase from 47.8 to 49.8, moving its ranking from 23rd to 22nd. This shift indicates improvements within China's higher education and research sectors. In tertiary education, China's score improvement from 20.4 to 20.6 raised its rank from 94th to 88th. The R&D sector saw an increase from 59.1 to 60.3, which advanced China's ranking from 17th to 15th. These gains are a testament to China's dedication to strengthening its innovation infrastructure.

China also made significant strides in global corporate R&D investments, improving its rank from 6th to 2nd as investments rose from 90.1 million USD to 92.9 million USD. Additionally, the QS University Ranking for China's top three universities climbed from 5th to 3rd, indicating a notable improvement in the quality of higher education.

The United States, South Korea, and Japan also featured in the rankings, with South Korea maintaining the top position consistently across the years. The United States displayed minor fluctuations but remained near the top, indicating strong performance in human capital and research. Japan's rankings exhibited some variability, reflecting the competitive nature of innovation in the higher education and R&D sectors.

2.2.3. China's Infrastructure

Figure 5.5. **Infrastructure Rankings (2018-2023): USA, Korea, Japan, China**



Infrastructure Ranking of China, 2018-2023

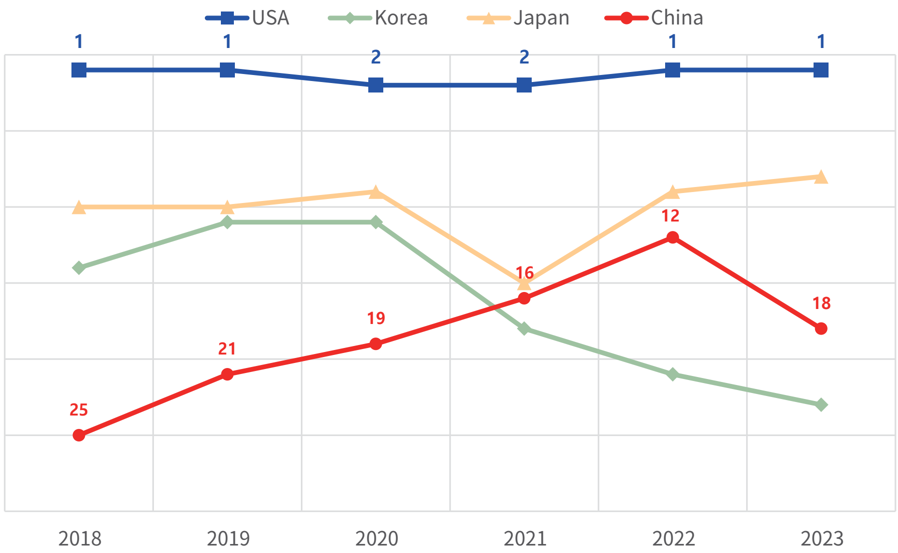
During the period from 2018 to 2023, China's overall infrastructure score in the GII witnessed a minor decrease from 56.8 to 56.4. Despite this slight decline, China's ranking improved from 29th to 27th. This improvement was partly due to significant advancements in Information and Communication Technologies (ICTs), with the overall ICT score jumping from 66.7 to 86.0. China's ranking in this sector improved dramatically from 45th to 18th, reflecting the government's strong push for online services and e-governance, which saw an increase in the government's online service score from 76.8 to 87.6.

The country also saw improvements in general infrastructure, notably in gross capital formation as a percentage of GDP, where China's score rose from 44.0 to 44.8. This advancement moved China's rank from 31st to 15th, showcasing its aggressive infrastructure investment.

However, ecological sustainability in China's infrastructure development is a growing concern, with the environmental performance score taking a steep decline from 50.7 to 16.1. This drop has significantly affected China's rank in this area, plunging from 96th to 118th, and highlights the environmental cost of China's rapid infrastructure development.

2.2.4. China's Market Sophistication

Figure 5.6. Market Sophistication Rankings (2018-2023): USA, Korea, Japan, China



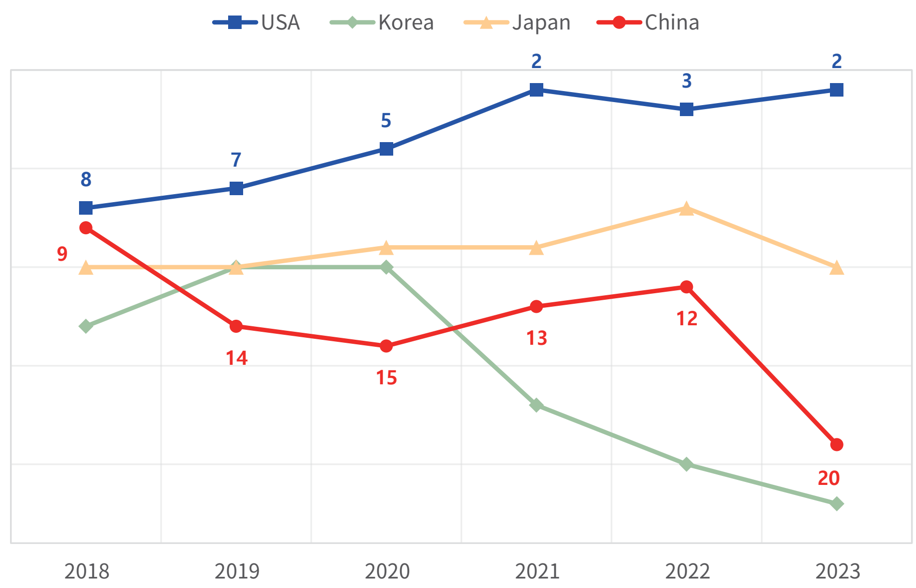
Market Sophistication Ranking of China, 2018-2023

China's market sophistication in the GII improved notably, climbing from 25th to 18th from 2018 to 2023, with its score rising from 55.6 to 56.7. The country advanced in domestic credit to the private sector as a percentage of GDP, increasing its score from 156.7 to 182.9 and moving from 7th to 4th rank. This highlights China's improved financial support to its private sector. In 2023, China added a new market sophistication category, scoring 99.8 and ranking 2nd, reflecting a highly diversified industrial sector. Its domestic market scale expanded from $23,122.0 billion to $30,074.4 billion, maintaining its top position.

Challenges persisted in VC investments, with the number of deals per billion PPP$ GDP steady at 0.1, dropping China's rank from 22nd to 36th. Nonetheless, trade, diversification, and market scale collectively improved, boosting China's score from 87.8 to 94.6 and advancing its rank from 2nd to a closer 3rd, nearly reaching the leaders.

2.2.5. China's Business Sophistication

Figure 5.7. **Business Sophistication Rankings (2018-2023): USA, Korea, Japan, China**



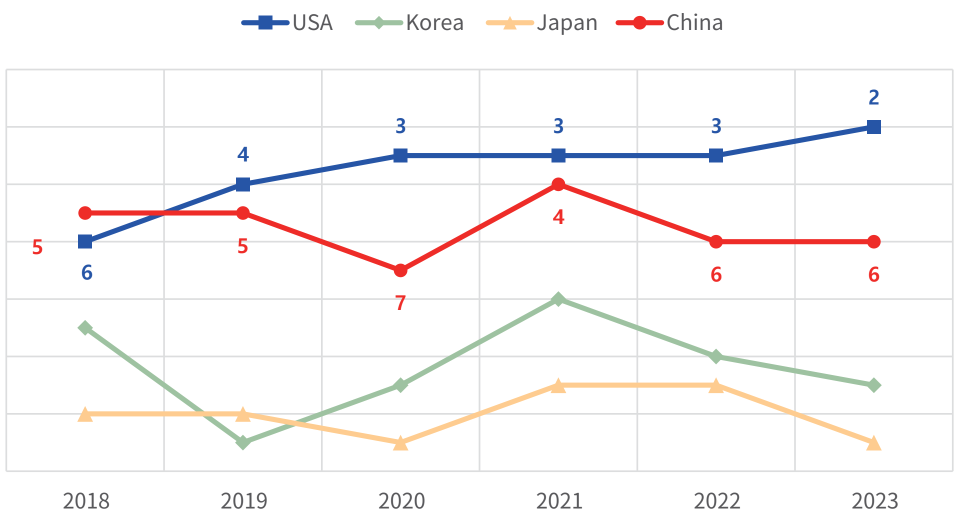
Business Sophistication Ranking of China, 2018-2023

From 2018 to 2023, China's ranking in business sophistication within the GII saw a decline, with the overall score dropping from 56.0 to 54.1 and its rank descending from 9th to 20th. This downturn was particularly noticeable in the knowledge workers category, where China's score significantly decreased from 85.6 to 66.1, resulting in a fall from 1st to 12th rank. However, not all indicators were negative; innovation linkages saw a rise in score from 30.7 to 43.8, maintaining the 27th rank, and there was significant progress in cluster development, with a score jumping from 59.6 to 91.4. This leap greatly improved China's rank from 26th to 2nd, suggesting a strengthening in business networks and clusters, which are essential for innovation ecosystems.

Despite the challenges in knowledge absorption as reflected by a slight decrease in the talent in businesses score from 61.9 to 58.5, there were areas of incremental progress such as intellectual property payments and patent families with multiple offices, both of which saw improvements in their scores and ranks.

2.3. China Innovation Outputs

Figure 5.8. **Knowledge and Technology Outputs Rankings (2018-2023): USA, Korea, Japan, China**



According to the GII, Innovation Outputs are categorized into two sub-factors: Knowledge & Technology Outputs and Creative Outputs.

2.3.1. China's Knowledge and Technology Outputs

Knowledge and Technology Outputs Ranking of China, 2018-2023

From 2018 to 2023, China's score for Knowledge and Technology Outputs in the GII saw an increase from 56.5 to 61.5. Despite this rise, China's ranking experienced a slight decrease, moving from 5th to 6th. This period highlighted China's substantial improvements in knowledge creation, with its score going up from 69.1 to 71.9 and the ranking advancing from 4th to 3rd. The country also showed progress in knowledge diffusion, with its score increasing from 37.0 to 47.2 and its rank improving from 22nd to 20th, suggesting a growing international impact of its innovation.

China's intellectual property receipts as a percentage of total trade leaped forward, with the score moving from 0.1 to 0.3 and the ranking jumping from 66th to 33rd, demonstrating China's enhanced capacity to leverage intellectual assets in global trade. Additionally, China maintained its lead in utility model patents, a reflection of its practical innovations, with a decline in high-tech exports' score from 28.7 to 28.0 and a slight shift in ranking from 1st to 5th.

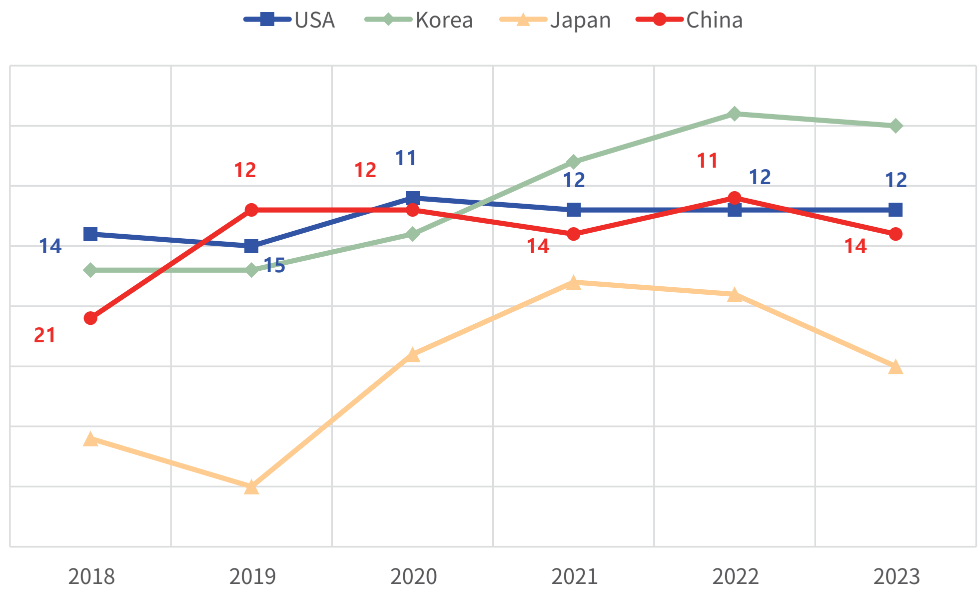
However, the country's ranking in the citable documents H-index, which measures the quality and quantity of scientific research, saw an improvement from 52.7 to 66.1, and China's rank rose from 14th to 11th, pointing to an enhancement in research recognition on the global stage.

2.3.2. China's Ranking of Creative Outputs

Creative Outputs Ranking of China, 2018-2023

China's ranking for Creative Outputs in the GII from 2018 to 2023 demonstrated significant improvement. The overall score increased from 45.4 to 48.9, and the country advanced from 21st to 14th place. This progress is indicative of China's growing influence in creative sectors, especially noted in intangible assets, where the overall score rose markedly from 71.9 to 80.5, securing a top rank. This rise was propelled by a substantial increase in trademarks by origin per billion PPP$ GDP from 165.7 to 337.9.

Figure 5.9. Creative Outputs Rankings (2018-2023): USA, Korea, Japan, China



Despite holding a steady rank in creative goods exports, China saw a slight overall decline in the services sector, with the score decreasing from 35.1 to 31.4, while the rank remained at 28th. This suggests some areas of challenge within the creative output landscape, including a decline in national feature films per million population aged 15–69, which saw a decrease, potentially indicating shifting consumption patterns and a more competitive global market.

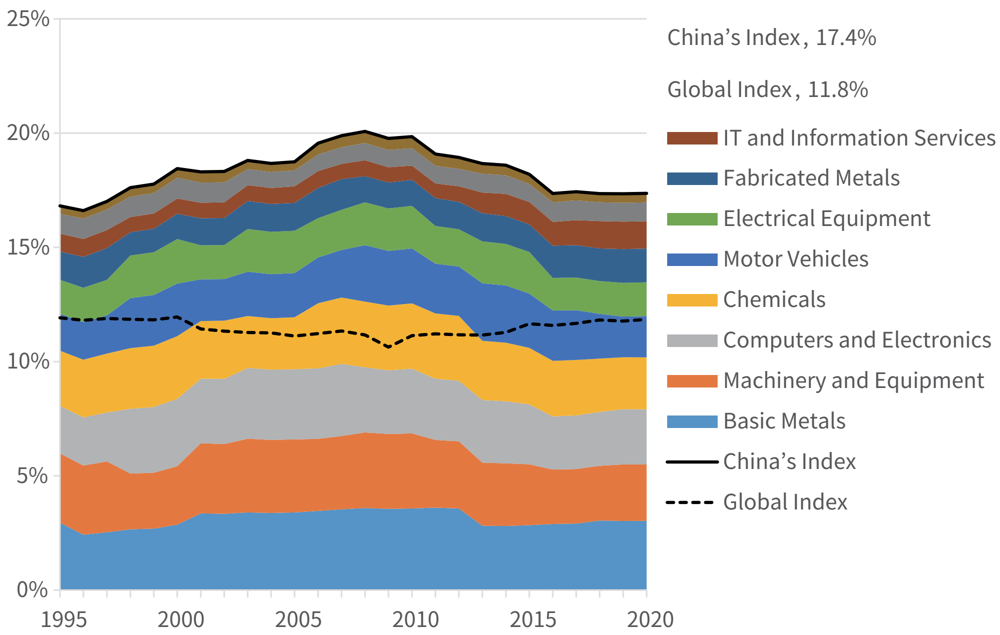
China also saw a notable boost in real online creativity, with the overall score improving from 2.8 to 3.1. This underscores the country's continued efforts to leverage the digital space for creative content, contributing to the robustness of its creative ecosystems.

3. Analysis of Innovation Outcomes by Hamilton indexes

3.1. China's Advanced Industry Performance

Until 2011, the United States led the global market in advanced industry output. However, the latest data indicates that China has now overtaken the U.S. to become the global leader in this area.

Figure 5.10. **Hamilton Index industries' shares of China's economy**



In the industrial landscape, China demonstrates superior performance in nearly all sectors, except for certain areas of transportation outside of automotive, which are currently being enhanced, notably with the development of COMAC's commercial aircraft ventures. Additionally, while China lags in software development within the IT and information services sector, it has established a significant presence in the basic metals sector, especially in steel production. This sector, historically supported by substantial subsidies, has achieved a Location Quotient (LQ) of 2.64, highlighting China's strong comparative advantage. The country also shows robust strengths in electrical equipment, machinery, chemicals, and computer and electronics manufacturing.

From the early 2000s up to 2020, there was a general decline in the LQ across most Chinese industrial sectors. Notable exceptions include the IT and information services sector, which has been buoyed by the expansion of tech giants like Baidu and Alibaba, as well as the fabricated metals sector. Despite this, after the implementation of President Xi's "Made in China 2025" initiative, the growth rate of China's LQ in the targeted sectors slowed down by 30 percent from 2015 to 2020, compared to the growth from 2010 to 2015. This slowdown indicates a strategic shift in the performance and advancement of China's strategic industries, in line with the nation's broader goals for economic transformation and policy direction.

Figure 5.11. China's relative performance in Hamilton Index industries (2020 LQ)

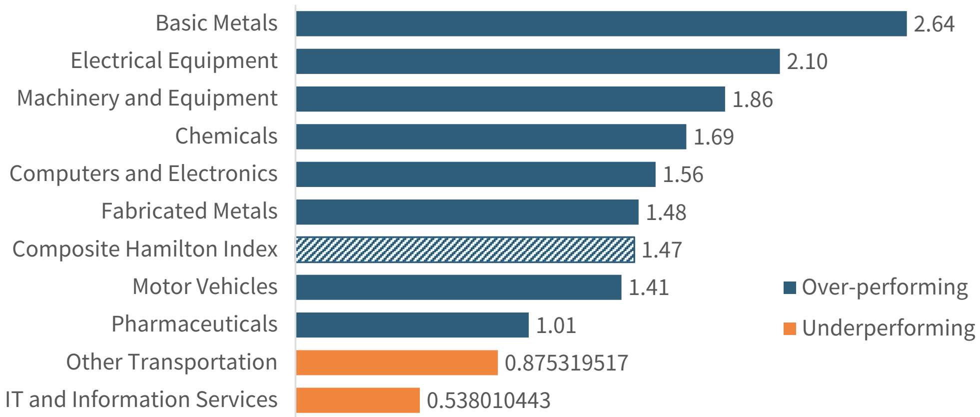
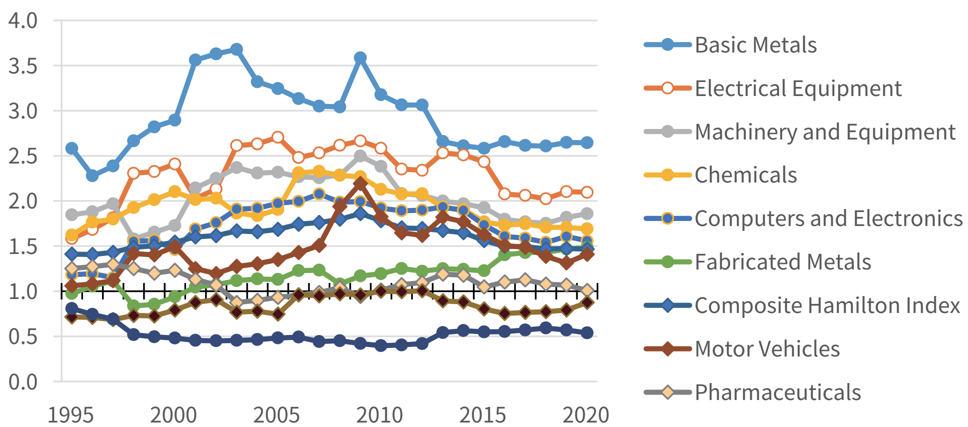
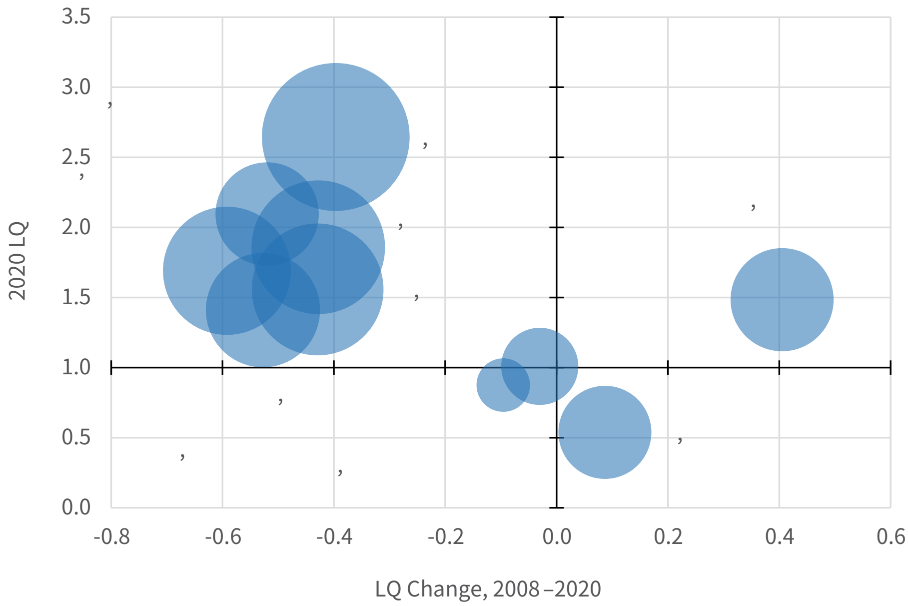


Figure 5.12. China's relative historical performance in Hamilton Index industries (LQ trends)



The analysis delineates ten industries through the prism of the Location Quotient (LQ), its evolution over time, and the industry's overall magnitude. Industries situated in the upper right quadrant, distinguished by an LQ surpassing 1 in 2020 coupled with a positive LQ trajectory from 2008 to 2020, are designated as both robust and burgeoning. In contrast, industries residing in the lower left quadrant are characterized by diametrically opposite attributes. Under this analytical framework, China's industrial landscape showcases a distinct presence in the "strong, growing" sector with its fabricated metals industry, which commands an impressive output of $216 billion. Concurrently, it harbors an industry within the "weak, growing" echelon: IT and information services, which, when benchmarked against the United States and other global contenders, displays a comparative frailty. Despite the fortitude of China's shipbuilding and railway sectors, they are categorized as "weak, declining ."However, the projected domestic edict mandating Chinese carriers to incorporate COMAC aircraft for domestic routes foreshadows an upward and leftward trajectory in the quadrant for this sector over the next decade.

Figure 5.13. China's net performance in Hamilton industries since 2008 (scaled to 2020 output)



Predominantly, China's industrial sectors are classified as "strong, declining". This label does not negate the growth within these sectors but highlights their expansion rate, which lags behind the broader pace of the Chinese economy. On the spectrum of overall dynamism, China registers a score of 257, lagging behind frontrunners like Taiwan, Singapore, Switzerland, and Korea, yet it still secures a score more than twice that of the United States.

3.2. Key Innovation Actors in China

China's innovation ecosystem benefits from a strong institutional framework at both national and provincial levels, ensuring a cohesive approach to technological development. The State Council, which is the pinnacle of administrative authority in China, is led by the Premier and includes heads of major ministries. It plays a crucial role in governing the country's innovation landscape.

The Ministry of Science and Technology (科学技术部), a key player in this system, is tasked with boosting the nation's scientific efforts and extending its responsibilities to technological innovation. MOST is central to developing the national innovation system, promoting science and technology (S&T) management reforms, and improving incentives for technological innovation across various government departments. Its activities are focused on enhancing the national research and development (R&D) infrastructure, reforming research institutes, encouraging enterprise innovation, fostering military-civilian integration, and supporting significant national S&T decision-making processes. Significantly, a substantial portion of R&D initiatives in China is driven by provincial and city governments, which allows for decentralized decision-making that could be more effective in certain contexts.

Established in 2008 through a ministerial reform, the Ministry of Industry and Information Technology (工业和信息化部) amalgamates responsibilities for industrial management, defense science and technology, and the information industry. Its creation aimed to streamline the integration of technological advancements with industrial development. The science and technology department within MIIT is pivotal in establishing policies and standards for high-tech industries, especially in fields such as bio-medicine, new materials, aerospace, and the information industry. This department is responsible for overseeing industrial technical specifications, quality management, and national S&T projects, thereby facilitating the integration of technological innovation with academic and industrial collaboration.

In addition to these ministries, China has initiated the formation of specialized innovation and technology institutions, such as the China Institute of Quantum Services, to secure leadership in emerging technologies like quantum technology. The establishment of Manufacturing Innovation Centers is another strategic endeavor to boost manufacturing innovation capabilities. These centers serve as national innovation platforms and are collaborative efforts involving enterprises, research institutes, and universities. They focus on the development, transfer, and commercialization of key technologies. Notable examples include the National Robotics Innovation Center and the National Innovation Center for High-end Intelligent Household Appliances, underscoring China's ambition to lead in technological innovation and industrial advancement globally.

3.3. China's NIS Strengths

More than the other four nations the state plays a stronger role in the Chinese S&T system. Not only do state-owned enterprises have a larger role in the Chinese economy than the other four, but Chinese S&T policies are more interventionist and stronger. However, "socialism with Chinese characteristics" still relies on markets and firms facing market pressures, unlike the Soviet Union.

While the CCP sets goals and directions (e.g., Made in China, 2025), it still allows firms and entrepreneurs considerable discretion (at least outside the political sphere). Overall, while the CCP has controlled the political sphere (e.g., liberal arts), the science and technology sphere is largely free because it knows that it needs to rely on bottom-up forces for innovation. At the same time, the state sets directions regarding technology direction more than any of the four other nations have. It sets goals for the industries and segments of industries in which China must grow. As the central government signals which areas are important, provincial governments follow suit, as do researchers, entrepreneurs, and companies. They know that they will be supported if they get into these targeted areas.

Everyone wants to be blessed if they are part of the project that the state wants. The problem here is that too many projects are supported, often ones of low quality.

In the realm of science and technology (S&T), China's state involvement is notably more pronounced than in four other major nations, with state-owned enterprises playing a crucial role and S&T policies being distinctly more interventionist. However, the principle of "socialism with Chinese characteristics" still integrates market dynamics and competitive pressures, setting it apart from the Soviet model. A significant advantage of China's NIS is the high priority that the country's top leadership places on technological innovation, a focus that is not as consistently observed in the United States.

The Chinese Communist Party (CCP) not only defines strategic objectives, as seen in the Made in China 2025 initiative but also grants a certain degree of freedom to firms and entrepreneurs, especially those operating outside the political sphere. While the CCP exercises control over political areas, it allows the science and technology sectors relative autonomy, acknowledging the value of grassroots innovation. This approach to steering technological advancement serves as both a strength, channeling resources towards pivotal S&T areas, and a potential weakness.

A notable strength of China is its emphasis on manufacturing and engineering, which is influenced by leadership that predominantly views issues from an engineering perspective. The country's extensive size and varied technological ambitions, combined with a substantial domestic market, facilitate technology transfer to local firms and attract foreign enterprises.

Compared to more developed economies, regulatory policies in China are less strict, and aimed at maintaining the country's attractiveness as a global investment destination without placing undue burdens on exporters. Additionally, China demonstrates a robust capacity for new business creation, surpassing Japan and Korea, bolstered by an education system that emphasizes entrepreneurship and significant venture capital availability. This model of "controlled entrepreneurship" ensures that start-up innovation aligns with national priorities, as exemplified by initiatives such as China's 100 Little Giants program.

Finally, a key strength of the Chinese NIS is the massive and growing size of its market. Coupled with restrictions on foreign market access to many advanced technologies, this market size lets Chinese companies gain considerable economies of scale and revenues to reinvest in R&D before ”going out” and competing with other nations. In addition, the market size gives the Chinese government a powerful lever to force foreign companies to share key technologies and capabilities in exchange for market access.

Related to this is the massive amounts of money the national and provincial governments provide for advanced industries, including semiconductors, solar panels, nuclear power, displays, aerospace, and others. At the end of the day, money is the largest enabler of innovation.

And that funding is a reflection of the almost single-minded focus of the CCP leadership on becoming the world's technology leader. In contrast to the other economies examined here, the overarching desire to achieve this mission is higher, and the CCP's ability to marshal societal resources and overrule objections is markedly higher.

3.4. China's NIS Weaknesses

First, the central government's approach to designating priority areas often leads to a cascade effect. Provincial governments, researchers, entrepreneurs, and companies swiftly move into these prioritized fields, resulting in an overabundance of projects. Not all these projects maintain high quality, as entities compete for state support and recognition within these targeted areas.

Indeed, there are some concerns that the system is too government-directed, where industrial associations and scientific associations are not relied on enough to communicate back to the leadership in a feedback loop to help their innovation system evolve more effectively. Moreover, reflecting its Leninist/Maoist tradition, the innovation system has been limited by bureaucratic restrictions and burdens. But in recent years, the state has worked to reduce the administrative burdens on research scientists and liberated them to do their research. In addition, while there was a trend away from state-owned enterprises in the past, that trend seems to have reversed. This reduction in the role of private companies serves as a damper on China's innovation system.

Second, China's innovation system's dynamic nature, which evolves based on lessons from past policy implementations and technological advancements, makes it vulnerable to trends and fads. This susceptibility has led to the rapid development of R&D parks and initiatives like pushing for dual listings in foreign stock markets, which may not always be sustainable or yield the desired long-term benefits.

Third, there's an insufficient engagement with industrial and scientific associations within the system. These associations could provide valuable feedback to refine and improve the innovation system. Despite some efforts to reduce bureaucratic barriers for researchers, the ecosystem still faces challenges, including governmental overreach that sometimes stifles innovation, such as the crackdown on IT entrepreneurs.

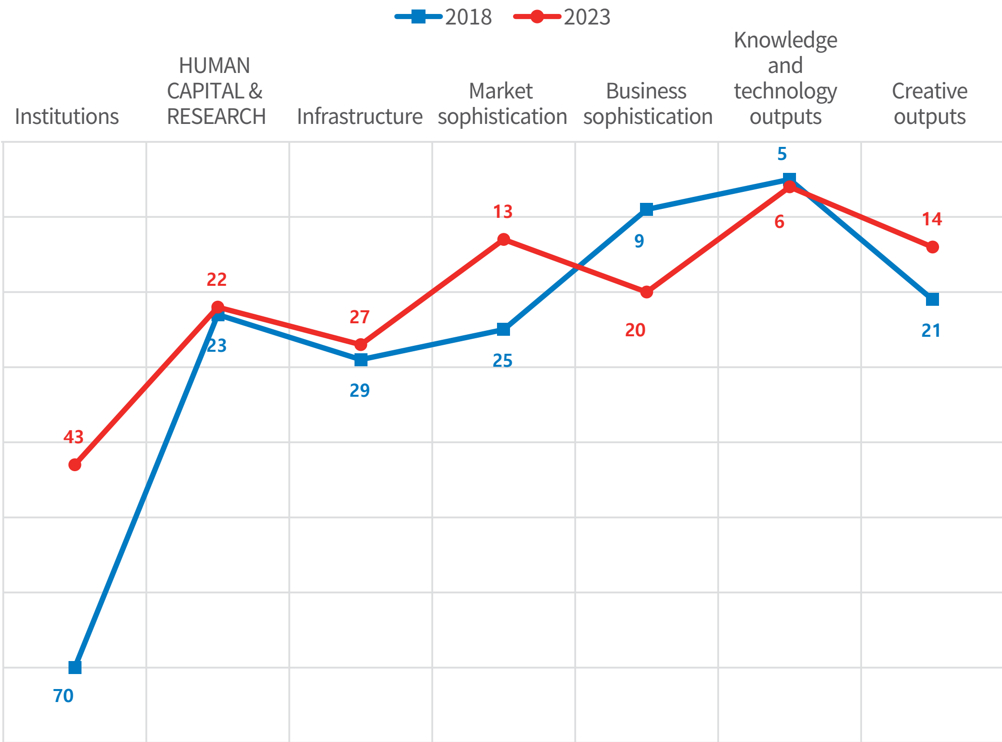
Fourth, China's assertive foreign policy complicates its efforts to integrate into the global innovation network. While there are moves to enhance international collaboration, such as inviting international S&T organizations and Nobel laureates to conferences, obstacles remain, especially in fostering open and cooperative relationships with global partners, including the U.S. Indeed, because of the assertiveness—some might say aggression—of China under Xi Jinping, China has "burned many bridges," severely limiting Chinese cooperation with many nations in the West.

Fifth, compared to leading nations, China's investment in basic research has historically been low as has been its research management system. This is reflected in part by the relative lack of Chinese research universities in the world's top ranking. Recognizing the crucial role of foundational science in driving both engineering and scientific innovation, the leadership is now placing greater emphasis on bolstering basic research to complement its strengths in applied science and technology development.

4. Implications and Conclusions

4.1 China's NIS perspectives

Figure 5.14. China's NIS Rankings Comparing 2018 and 2023



This study investigates China's NIS by analyzing the GII and Hamilton Indexes from 2018 to 2023, focusing on Innovation Inputs, Innovation Outputs, and Innovation Outcomes. The results of the GII reveal three noticeable trends: Despite the Chinese government's stringent controls over Innovation Inputs, there are expectations of continuous improvements and investments in institutions, human capital research, and infrastructures. However, market sophistication and business sophistication factors are anticipated to hinder China's NIS performance due to the challenging business environment.

In terms of innovation outputs, it is anticipated that tangible assets of knowledge and technology will maintain China's competitive position. Nonetheless, the intangible assets, particularly creative outputs, are expected to decrease in the foreseeable future.

4.2. ICRD Case

One distinctive feature of China's NIS is its state-controlled, top-down system. Beyond the roles of the Communist Party, the Ministry of Science and Technology (MOST), and the Ministry of Industry and Information Technology (MIIT), local governments, Chinese universities, and state-owned enterprises collaboratively forge innovation outcomes in specific industries. A significant focus of these innovation outcomes is achieving global market share, as exemplified by the 'Made in China 2025' initiative. China has met many of its goals in key global industries, with the notable exceptions of the ICT and pharmaceutical sectors, which have faced challenges due to sanctions imposed by the Biden Administration in the USA on materials, parts, and equipment for advanced semiconductor chips.

In response to these sanctions, China has been actively working to overcome technological barriers in integrated circuits (IC) by fostering a semiconductor ecosystem aimed at the research and development of not only semiconductor chips but also semiconductor materials, parts, and equipment. A prominent example of this effort towards indigenous innovation within the chip ecosystem is the National IC Innovation Center in Shanghai. This research institution, supported by the Shanghai Government, Fudan University, and the Semiconductor Manufacturing International Corporation (SMIC), exemplifies China's strategic approach to sustaining and advancing its technological capabilities amidst international challenges.

Figure 5.15. **China Semiconductor Ecosystem**

Collaborations between upstream and downstream firms in China's semiconductor ecosystem are leading to business successes, fostering a positive cycle that enhances the competitiveness of semiconductor companies, supported by the ICT, mobile, and internet sectors.

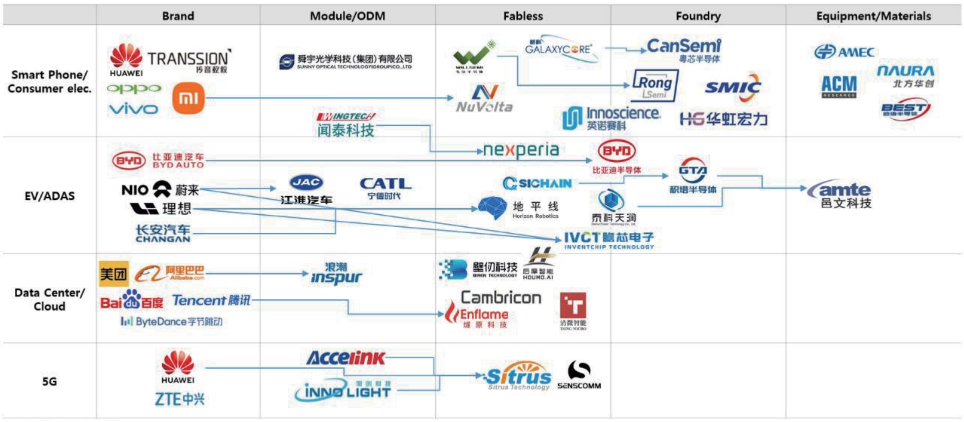
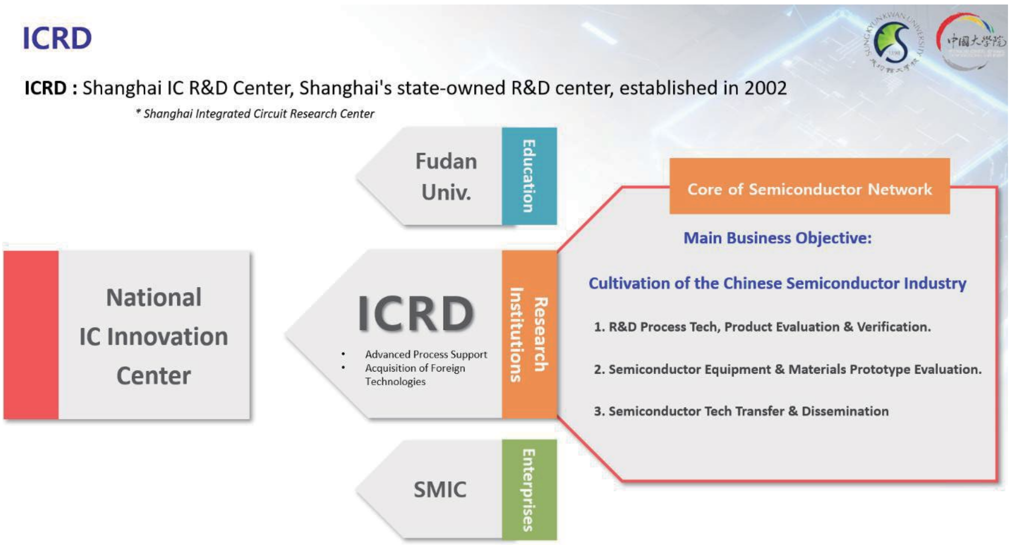


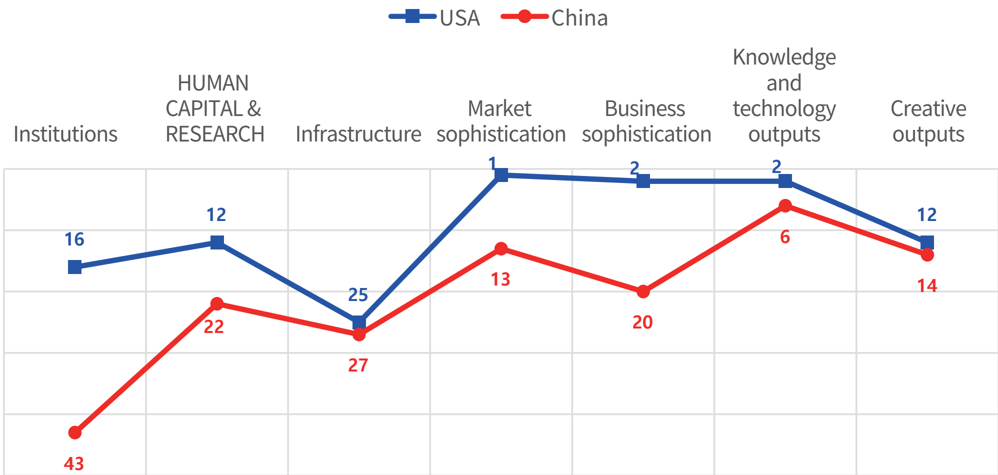
Figure 5.16. **ICRD cases**



The IC R&D initiative plays a pivotal role in nurturing the Chinese Semiconductor Industry, focusing on acquiring foreign technology and products. This strategy involves re-engineering materials, parts, and equipment from globally advanced semiconductors. The goal is to transfer and disseminate these innovations across various state-owned and private enterprises to expedite the process of bridging technological gaps. However, it's important to note that many of these practices, observed as efforts to accelerate technological catch-up, may be considered patent-infringing and illegal in Western societies.

4.3. Comparing NIS between USA & China

Figure 5.17. NIS Rankings Comparing USA and China in 2023



- In 2023, this study initiated a comparative analysis of the National Innovation Systems (NIS) and the Global Innovation Index (GFI) between the USA and China.
- The findings indicate that China's NIS is quickly closing the innovation gap with the USA, demonstrating significant strides in enhancing its innovation capabilities.
- Nevertheless, despite China's rapid progress, the USA's NIS maintains a superior competitive edge, especially in terms of innovation inputs.

4.4. Perspectives of China NIS

China's S&T sector is distinguished by significant state involvement and strategic policy-making, emphasizing technological innovation and fostering grassroots innovation through programs like "Made in China 2025." The sector benefits from a focus on manufacturing and engineering, supported by a vast domestic market and a regulatory environment conducive to attracting foreign investment. The education system is tailored to encourage entrepreneurship, aligning with national priorities.

The centralized designation of priority areas in China's S&T sector often results in an oversupply of projects of varying quality, with a tendency towards unsustainable trend-based developments. Limited engagement with industrial and scientific associations, combined with governmental overreach, can hinder innovation. China's assertive foreign policy and historically low investment in basic research challenge its integration into the global innovation network despite efforts to boost foundational science.

China's innovation landscape transformation commenced with the "indigenous innovation" initiative in 2006, aimed at boosting domestic innovation through the assimilation and re-innovation of imported technologies, progressing to the Made in China 2025 strategy that emphasizes market-driven "smart" manufacturing and intellectual property protections. Despite notable advancements, challenges such as optimizing state involvement and ensuring productivity growth persist, underscoring China's evolving but significant influence on global technological competitiveness and innovation trends.

4.5. Conclusions

The Chinese National Innovation System (NIS) operates under a highly effective state-controlled framework, demonstrating substantial progress in harnessing imitative innovation to dominate global market shares across several major industries. Despite notable successes, exceptions exist in sectors such as integrated circuits (IC), semiconductors, and pharmaceuticals, with limited data on emerging innovative fields like AI, quantum computing, robotics, and the IC industry. This reflects a broader spectrum of achievements and areas for potential growth.

The state-controlled approach has been instrumental in enabling China to catch up with global innovation leaders such as the USA, Korea, and Japan, particularly in terms of innovation outcomes and global market share. However, this paper asserts that such a system may not be as effective in fostering creative innovation. Evidence suggests that decreasing market and business sophistication, influenced by economic policies under Xi Jinping, could negatively impact R&D and venture capital investments from international companies. This scenario outlines a challenge for China's NIS in transitioning from imitative to indigenous and creative innovation.

Anticipating the future direction of China's NIS involves recognizing a strategic shift towards open innovation. This adjustment aims to alleviate the constraints imposed by tight government control and encourage a more collaborative innovation ecosystem with global companies. Such a move is predicted to enhance investments in Chinese venture capital and ventures, signaling a pivot from purely indigenous innovation strategies to those that embrace global partnerships and open innovation paradigms.

Through comparative analysis with five other countries, this study has deepened our understanding of the complexities and dynamism of China's NIS. It is clear that while the system has been effective in achieving certain targets and establishing a significant presence in global markets, the evolving nature of global innovation necessitates a reassessment of strategies to ensure sustained growth and leadership in creative innovation.

In conclusion, China's National Innovation System has shown remarkable efficacy in leveraging state control to achieve rapid advancements and market dominance in several key industries. Yet, to cultivate a thriving environment for creative innovation and maintain its competitive edge on the global stage, strategic realignments focusing on open innovation and international collaboration are essential. This transition represents not only an adaptation to the challenges posed by internal and external economic policies but also an opportunity to redefine China's role in the future of global innovation.

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Chapter 6

Japan

Stephen EZELL

As Peter Hall and David Soskice write in *Varieties of Capitalism*, Japan can be characterized as a "coordinated-market economy," which relies on formal institutions—in particular, powerful agencies such as Japan's Ministry of Economy, Trade, and Industry (METI)—to regulate the market and coordinate the interaction of firms and firm relations with suppliers, customers, employees, and financiers.[1] While Japan is a market-based economy, Japan's government has been heavily involved in shaping the direction of the economy and supporting the development of critical strategic industries and enterprises therein. It does so through close linkages with the private sector, particularly leading industrial conglomerates (e.g., the *keiretsu*). Japan's approach has given rise to world-leading industrial firms; however, Japan's economy suffers from relatively low productivity rates, underperforming domestic services sectors, and weak rates of entrepreneurship. In total, Japan's national innovation system (NIS) can be characterized as largely top-down and heavily government-coordinated, particularly in collaboration with leading industrial firms, with an approach that features significant industry-led, technology-focused research and development (R&D) investments and missing much of the "bottom-up" type, entrepreneurial innovation dynamics more characteristic of the United States. It is also relatively stronger on the engineering part of the science-engineering continuum. This chapter examines the history and current state of Japan's NIS, highlights its key actors and inputs, and considers the state of Japan's industrial performance before examining several challenges that hold back Japan's innovation performance.

1. History and Evolution of Japan's NIS

The history of Japan's NIS goes back over 150 years. As Shashank S. Patel explains, Japan's original innovation system was established in 1868 during the Meiji Restoration, with the chief goals of modernization, education, high-tech imports, and public-private partnerships.[2] Yet most of the institutions that constitute Japan's highly cooperative industry-government behavior were adopted in the interim between the two World Wars.[3] As Chalmers Johnson wrote in *MITI and the Japanese Miracle*, "it was conscious institutional innovation which began to shape the Japanese system in the first two decades of this century, perfected the system of enterprise familism (or what one might call corporate paternalism) in the 1930s, and revamped the system to accommodate the new strength of unions in the late 1940s to produce what is the 'welfare corporatism' of today."[4] Characteristic of Japan's pre-war economy (and dating back to the Meiji era), were the *zaibatsu*, which refers to industrial and financial vertically integrated business conglomerates in Japan, of which there were four main ones—Mitsui, Mitsubishi, Yosuda, and Sumitomo—and several other, "second-tier" ones (including Nissan and Kawasaki).[5] After WWII, the United States would seek to dissolve the *zaibatsu*, but it failed to completely disassemble the system, as many subsidiaries and smaller groups survived—of the 235 subsidiaries targeted, only 25 were actually dissolved—and out of these emerged the *keiretsu* system, interconnected networks of Japanese companies characterized by strong alliances and cross-shareholding.[6]

Economists Masahiro Okuno-Fujiwara and Laura D'Andrea Tyson have defined three periods of Japanese industrial policy following WWII in which different policy tools were implemented to spur Japan's technological and economic development.[7] The first period (1945–1960) was defined by regulated markets via price controls, rationing, and prioritization of the coal and steel industries. It was also in these decades immediately following World War II that Japan's technological development was spurred along by a series of controls on technology and foreign direct investment (FDI) inflows and protection for firms in industries the government designated as important to further economic development.

During the post-war period, Japan largely shielded its economy from foreign competition, with very tight restrictions on inbound foreign direct investment and foreign product sales. Its large domestic population meant that firms in protected key industries found sufficient demand at home and did not have to compete in international markets if they were unable to. A robust, METI-led industrial policy targeted key industries such as automobiles, electronics, pharmaceuticals, shipbuilding, and construction machinery (among others), helping firms in these industries with technology upgrading, market protections, and export subsidies. Japan's well-educated population—particularly in the areas of science and engineering—meant the country was able to adapt and improve upon technologies imported from abroad and move up the value chain in key industries. It's also been noted that Japan's lack of military investment—America provided its defensive shield in the post-war era—meant that more resources could be devoted to commercial research and development (R&D) to improve upon products and technologies.

These dynamics produced the so-called Japanese economic miracle, as from 1955 to 1990, Japan's economic growth averaged 6.8 percent per year and its GDP multiplied eight times.[8] In 1979, Harvard economist Ezra Vogel predicted that Japan would surpass the United States as the world's leading economy.[9] But beginning in the early 1990s, Japan's economic growth began to stagnate, originally hit by a bursting real estate asset bubble and then by the 2008 Great Recession and a series of incidents from earthquakes to the Fukushima nuclear incident. Japan's economic stagnation from 1990 to 2010 has since been called "The Lost Decades."[10]

Several Japanese governments attempted to introduce science, technology, and innovation strategies to combat the decline, though to limited degrees of success. In 1995, Japan enacted the Science and Technology Basic Law, which sought to introduce an integrated government policy toward science and technology. The policy introduced successive five-year S&T Basic Plans, defining different priority fields and reflecting important goals including strengthening Japan's scientific and technological capacity and advancing Japan's industrial competitiveness.[11] In 2006, Prime Minister Shinzo Abe introduced the "Innovation 25" initiative, which exhibited the government's desire to increase the international relevance of Japanese innovation and to connect innovation to changing social values.[12] This was part of Abe's "Three Arrows" economic revitalization agenda—also known as "Abenomics"—which attempted to introduce structural reform, monetary easing, and more flexible fiscal policy measures to Japan.[13] This period also saw the country make important reforms to its intellectual property (IP) laws, including the promulgation of the Basic Law of Intellectual Property in 2002, the extension of patent protections to software, and the introduction of Bayh-Dole-like legislation, giving universities ownership rights to the IP stemming from federally funded research.[14] Despite these improvements, Japan's overall economic trendlines continued: Apart from leadership in select high-tech manufacturing industries (e.g., automotive, electronics, robotics, semiconductor manufacturing equipment), Japan's overall economic stagnation continued and its low-productivity domestic services sector and weak entrepreneurship levels persisted.

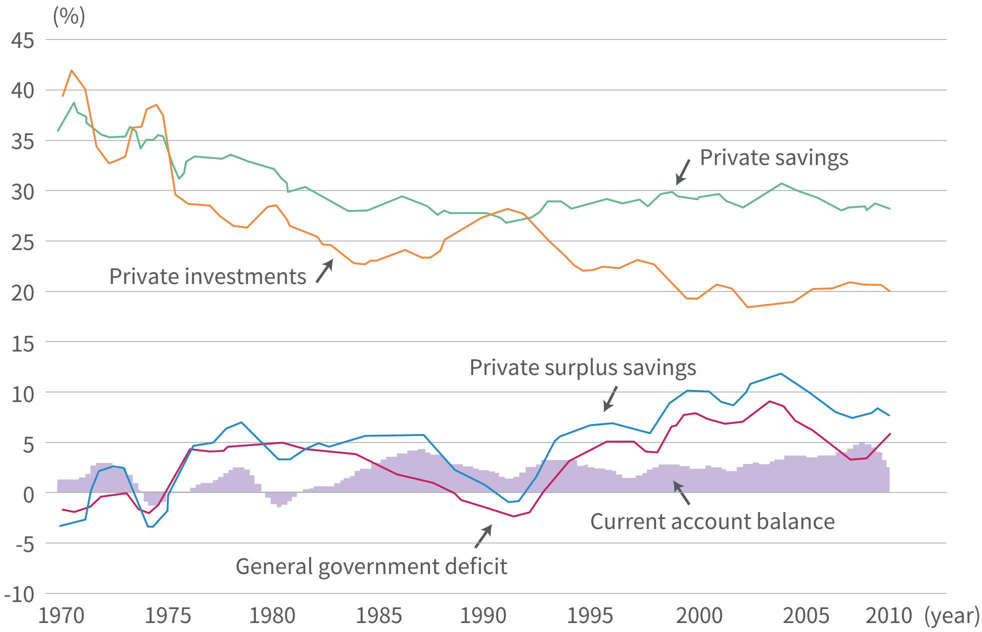
2. Analyzing Japan's Lost Decades

The Plaza Accord appears to have played a significant role in helping instigate Japan's lost decades. The G5 countries—France, Germany, Japan, the United States, and the United Kingdom—signed the Plaza Accord (better known as the Plaza Agreement) in 1985 with the principal intention to correct trade imbalances between the United States with Germany and Japan by weakening the U.S. dollar. In the five years leading up to the Accord, the U.S. dollar had appreciated by 47.9 percent, making U.S. imports cheaper and weakening the U.S. manufacturing sector. The agreement led to the yen and Deutsch mark appreciating significantly, while the dollar depreciated by as much as 25.8 percent in the ensuing two years.[15]

The rapid appreciation of the yen "led to a major short-term shock to Japanese export-based industries" to which the Japanese government responded with a "massive campaign of expansionary monetary and fiscal policy in a bid to boost the domestic economy."[16] This macroeconomic stimulus contributed to significant asset price bubbles in Japan's financial and real estate markets through the late 1980s, and when that bubble burst Japan began to experience a prolonged period of low growth and deflation that was to endure for the ensuing two decades.[17]

Other economists contend that underlying structural factors, such as Japan's surplus savings rate, ultimately contributed significantly to Japan's economic bubble and its subsequent bursting. Kyoji Fukao, a faculty fellow at Japan's Research Institute of Economy, Trade, and Industry, contends that Japan's surplus savings in the mid-1970s were initially invested overseas, but as this led to the U.S.-Japan trade imbalance and subsequent tensions with the United States (and thus the Plaza Accord) this subsequently meant the "focus of Japanese policies shifted to domestic demand expansion."[18] As Fukao writes, "[Thus] the bubble economy also resulted from surplus savings. … The Japanese government chose to promote private investment by lowering interest rates to counter the appreciation of the yen, and this resulted in the bubble economy."[19] (See Figure 6.1).

Figure 6.1. Changes in the savings-investment balance in Japan[20]



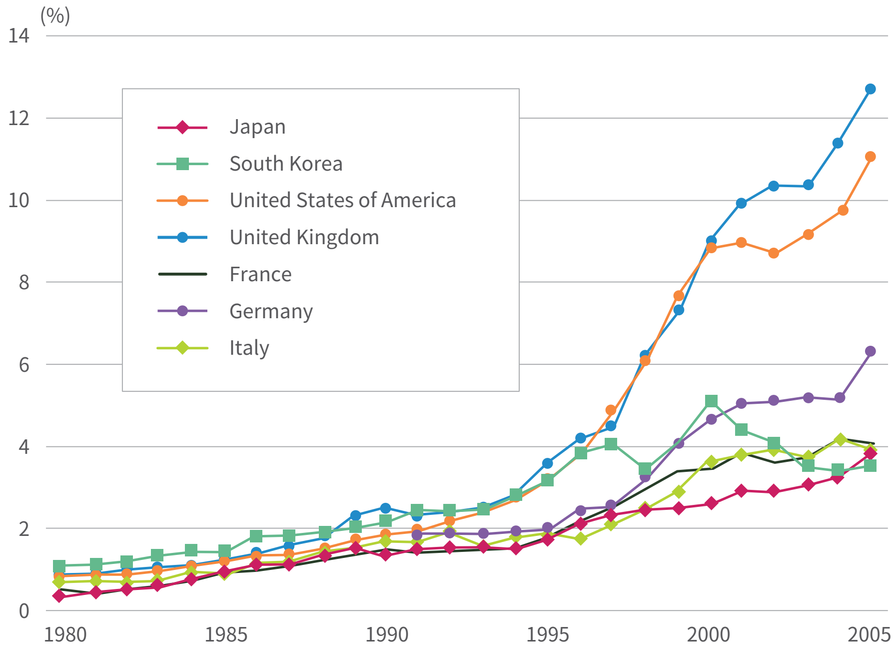
While that helps explain what caused Japan's economic bubble and its bursting, Fukao proceeds to explore other factors that contributed to prolonging Japan's lost decades and delaying the economic recovery. In his (2010) paper, he observes that "[Japan's] capital-labor ratio has been rising during the last two decades. This makes it unlikely that a lack of investment was the culprit for the weak growth."[21]

However, Fukao observes that, from 1995 to 2005, rates of ICT investment began to significantly diverge between the United States (and the United Kingdom) and Japan. (See Figure 6.2).

As Fukao writes, "this low ICT investment was one of the causes of sluggish growth in Japan."[22] In part, Fukao attributes this dynamic to the fact that Japanese companies prefer customized software, whereas U.S. companies are more willing to implement off-the-shelf software. As he elaborates:

Japanese companies invest more in customized software that only they can use, instead of highly versatile package software. Many companies can use low-priced package software in the United States because their organizations are flexible and can be reorganized. U.S. companies can change their organizations to suit the software. In contrast, Japanese companies are comparatively inflexible, and it is difficult for them to modify their organizations in response to the requirements of software. Consequently, Japanese companies use primarily customized software, enabling them to keep their organizations as they are. Since customized software is expensive and is not competitive, Japanese companies do not often make major ICT investments.[23]

Figure 6.2. Ratio of ICT investments in GDP in major industrial countries



Fukao cites another structural challenge that, since "the costs of opening and closing business establishments are very high" this contributed to the fact that "productive large companies did not expand their market share."[24] This of course speaks to the challenge of Japan's "zombie firms." The term refers to uncompetitive enterprises effectively being kept alive with direct interest rate subsidies (i.e., firms whose borrowing costs were so low that the only possible explanation for the low rates was that the banks were subsidizing them).[25] By 2001, zombies accounted for more than 15 percent of listed firms in Japan.[26] And, as one report found, the "zombie firm problem in the manufacturing sector was just as serious as the non-manufacturing in terms of firm count."[27] A 2008 study by Caballero, Hoshi, and Kashyap found that the presence of zombies in the 1990s significantly depressed profits, productivity, and investment in Japan. In particular, they estimated that investment was between 4 percent and 36 percent lower in the 1990s than if the share of zombie firms had remained at historical averages.[28] Hoshi contends that to deal with Japan's challenge of zombie firms (which spiked again in the wake of the COVID-19 pandemic), Japanese policymakers need to find ways to protect workers without shielding inefficient companies.[29]

3. Landscape of Japan's NIS in the 21st Century

In 2016, Japan introduced the Society 5.0 strategy (this was actually the core concept behind the 5th Science and Technology Basic Plan), which sought "to establish a better, super-smart and more prosperous human-centered society, with the support of technological innovations."[30] Japan's Society 5.0 envisions, "A human-centered society that balances economic advancement with the resolution of social problems by a system that highly integrates cyberspace and physical space."[31] Essentially, Japan's Society 5.0 is the equivalent of the "Industry 4.0" plans promulgated by countries such as Germany, which seek to advance national economic competitiveness and societal transformation through digitalization.

But while the Society 5.0 strategy has been an important animating instrument for digitalization in Japan, the country's innovation performance has continued to slide. In fact, Japan's ranking on the Bloomberg Innovation Index fell from 2nd place in 2016 to

12th place in 2021.[32] Similarly, Japan ranked just 13th in the 2022 edition of the Global Innovation Index.[33]

In light of its sliding innovation rankings, on June 9, 2023, Japan's government unveiled a new Integrated Innovation Strategy 2023, which outlines a growth strategy based on a mix of science, technology, and innovation policies.[34] Japan highlights three major pillars of their strategy:

1. Foster the development of the technologies that support the future of the country and guide their application in society, keeping in mind the superiority and indispensability of the technologies. This is meant to promote R&D in sustainable and green energy technologies.
2. Advance international brain circulation to create a source of science, technology, innovation, and value creation. This would involve promoting and expanding STEM internships for current students, strengthening international research initiatives with other G7 nations, and providing open access to scientific data and research papers.
3. Bring the benefits of science, technology, and innovation to the public and society by placing a priority on startups. This would include new support from the Small Business Innovation Research (SBIR) program to facilitate the adoption and subsequent societal diffusion of advanced technologies by startups.[35]

This agenda is to be further empowered by Japan's creation, in November 2021, of an $88 billion "University Fund" that will provide public money to major research universities to accelerate and enhance R&D and increase technology transfer to the commercial sector.[36]

Japan is certainly to be commended for its promulgation of comprehensive national innovation strategies, and willingness to invest heavily in R&D; however, as the latter parts of this chapter document, if the country is truly to reinvigorate its innovation competitiveness, it will need to tackle structural challenges such as low productivity and weak entrepreneurship rates (which will require addressing cultural and social issues as well), not just produce technology-driven innovation strategies.

3.1. Key Innovation Actors in Japan

As noted, Japan's Ministry of Economy, Trade, and Industry is the country's principal innovation agenda-setting institution, aiming to enhance Japan's industrial technology capabilities, enable private-sector innovation, and advance a variety of government initiatives for enriching intellectual resources.[37] In general, there is much more coordination between policymaking agencies and the business community in terms of national goals and economic/technological development in Japan than in the United States. While formal government-industry channels have become less prominent in recent decades, informal channels and *moral suasion* on behalf of policymakers remain important, and Japanese companies have the national interest in mind much more so than do U.S. companies—though government-industry alignment in Japan varies by industry.

Another key player is the New Energy and Industrial Technology Development Organization (NEDO), a national research and development agency that creates innovation by promoting technological developments necessary for the realization of a sustainable society.[38] Also playing a role (especially with the disbursement of R&D monies to universities and facilitating international education opportunities) is Japan's Ministry of Education, Culture, Sports, Science, and Technology (MEXT).[39]

Also playing an important role in promoting industrial competitiveness, especially among small- to medium-sized enterprises (SMEs) in Japan, are its Public Industrial Technology Research Institutes, or Kohsetsushi Centers. These were initially established in the late 19th century to support agriculture, textiles, and brewery (e.g., sake and soy sauce) sectors, but over the years have evolved to support manufacturing more generally.[40] The Kohsetsushi centers act as innovation intermediaries that perform three key roles in regional innovation systems in Japan:

They diffuse technological knowledge through various routes, such as testing, use of analytical equipment, technical consultation, joint research, and seminars for engineering education; they conduct their own research, patent inventions, and license patents, mainly to local SMEs; and they act as a catalyst for local SMEs to develop innovative networks to external sources of knowledge.[41]

Additionally, they have assisted SMEs in adopting various emerging technologies including sensor-enabled (e.g., smart) devices; embedded intelligence; advanced machining; nanotechnology; robotics; automation; microelectromechanical systems (MEMS); and computer numerically controlled machines. They also provide opportunities for SME research staff to gain research experience, develop new technical skills, and transfer technology back to their firms by working on Kohsetsushi Center projects.[42]

Just like in Germany, with its *Middelstand*, or largely private, medium-sized industrial companies, Japan boasts its *chuken kigyo* that dominates specialized industrial global markets. In fact, according to METI, Japanese companies serve more than 70 percent of the worldwide market in at least thirty industrial technology sectors worth more than $1 billion apiece.[43] The Kohsetsushi centers are critical support instruments for the *chuken kigyo*.

There are currently a total of 667 Kohsetsushi branches in Japan, with a staff of over 6,000.[44] Of those, 67 branches, corresponding to industrial agglomerations across all 47 prefectures, are dedicated specifically to manufacturing.[45] Japan's Kohsetsushi network received $2.14 billion in 2012.[46] However, since 2000, most local governments have been drastically reducing budgets for Kohsetsushi Centers, reflecting a substantial reduction in state aid.[47]

3.2. Key Innovation Inputs in Japan

Research and development (R&D) is becoming increasingly important for advanced economies. In the case of Japan, R&D, and the resultant innovations, are proving to be especially important for economic growth. This is because the country cannot realistically expect to grow via increases in the labor force. Thus, the country must look to solutions aimed at raising the productivity of its workers and businesses.

In 2020, the single largest source of R&D investment was public R&D, which constituted about 53 percent of spending. The second-largest source was universities, at about 40 percent. The remaining 7 percent comes from private companies (about 4 percent) and other non-profit organizations (about 3 percent).[48] The proportion of R&D invested by private companies is lower compared to other countries such as the United States (about 13 percent), France (about 17 percent), and South Korea (about 20 percent). In terms of who received government spending on R&D, 53 percent went to other public institutions. Additionally, 40 percent of government R&D went to universities, with the remaining 7 percent going to private companies (5 percent) and non-profit organizations (2 percent). The share of public R&D is quite low compared to other countries such as the United States (about 15 percent), the U.K. (about 18 percent), and South Korea (about 20 percent).

Historically, before the late 2000s, Japan was one of the leading countries in terms of R&D expenditures. Between 1981 and 2007, R&D rose from around 7 trillion yen to about 18 trillion yen. As a percentage of GDP, R&D over that same period rose from about 2.0 percent to 3.3 percent. However, since about 2007–2008 R&D has remained constant both in absolute terms and as a percentage of GDP. Starting in 2008, China surpassed Japan in terms of its R&D expenditure at about 17 trillion yen (about $115 billion) and continued rising to the equivalent of about $450 billion in 2022. Additionally, in 2009, Korea surpassed Japan in R&D as a percentage of GDP.

On the personnel side of things, Japan's number of researchers per 10,000 persons has stayed roughly constant since the early 2000s, at around 50–55 per 10,000 persons. South Korea surpassed Japan in this regard around 2009. Additionally, Germany caught up to Japan on this metric by 2020, with the United States, United Kingdom, and France also closing their gaps with Japan.

The R&D tax credit is a considerable driver of business R&D investment. Per the OECD, R&D tax incentives constituted 83 percent of all government support for business R&D, with a rate of 2–14 percent for large firms and 12–17 percent for SMEs with less than 250 employees from 2021 to March 2023.[49] However, there is still room for improvement in terms of the tax and subsidy environment. While Japan's R&D tax incentives are more generous compared to those of the United States, Australia, and South Korea, Japan ranked 18th in tax credit generosity in 2020.[50]

As Japan has approached the innovation frontier and moved to more advanced emerging industries, it has had to rely more on foundational research and incentives to innovate. This entailed policy coordination between government and industry officials to pursue developments in key technologies and research areas, as well as state-sponsored research projects that both funded research that private industry could or would not on its own and facilitated the transfer of new knowledge between companies.

Here, one could make the argument that Japan's METI-led, coordinated economy approach did succeed in the post-war era, up to the 1990s, in helping Japanese companies catch up to the global production frontier, and get competitive in industries like automotive, pharmaceuticals, and information and communication technologies (ICTs) like semiconductors. However, once having caught up, Japan has experienced much more difficulty in taking leading positions in the industries emerging since: biotechnology, software, the digital economy, and the sectors it spun off such as social media and artificial intelligence. Indeed, there's a risk that when governments are directing too much of the innovation policy agenda, firms themselves aren't learning innovation techniques.

In some sectors, Japan has also suffered from a "Galapagos Island" syndrome, where isolated markets and technology standards meant that Japanese companies weren't able to scale globally. For instance, consider Japan's telecommunications industry, where Japanese mobile phone enterprises chose to focus primarily on domestic markets for arguably very innovative mobile products, but the products couldn't compete at scale in global markets.[51] Overall, Japan does retain some very globally competitive advanced-technology industries, but even in many of these, their competitiveness is waning, as the following section elaborates.

4. Japan's Performance in Advanced Technology Industries

In the aforementioned 2021 Bloomberg Innovation Index, Japan ranked in the global top ten for R&D intensity (5th), manufacturing value added (7th), and high-tech density (10th). Where Japan lags behind many of its comparable high-income competitors is in the area of productivity (37th). The OECD notes that Japan's low productivity is especially troubling, given that the country cannot simply rely on labor force growth, due to population aging. The OECD also notes that firm productivity between firms at the frontier and laggards is much greater in Japan than in other OECD member countries and that a likely culprit is slow technological diffusion.[52]

During the 25 years from 1995 to 2020, Japan experienced significant declines in its share of global markets in advanced industries. In 1995, Japanese firms comprised significant shares of the world market in electrical equipment (34 percent), machinery and equipment (29 percent), and computers and electronics (27 percent). By contrast, in 2020, Japan's global market shares in those industries were 10 percent, 12 percent, and 5 percent, respectively. In particular, the industries that experienced the biggest declines in market share over that period were computers and electronics (-80 percent), other transportation (-75 percent), electrical equipment (-71 percent), and pharmaceuticals (-71 percent). The case of pharmaceutical manufacturing has been the subject of previous ITIF research.[53] (See table 1.)

Japan's decline in global market shares in these industries is very much a symptom of its underperformance relative to other nations. ITIF has developed the concept of the location quotient (LQ) to measure the performance of a country relative to the rest of the world in key industries.[54] The LQ is calculated as an industry's share of a country's output divided by that same industry's share of the world's output. In essence, it shows whether a country's key industries are over- or under-performing their global peers.

Within the traded sector, Japan's strongest advanced industries in 2020 were machinery and equipment (LQ of 1.96) and motor vehicles (1.69). Those scores represented an increase of 22 percent for machinery and equipment and 27 percent for motor vehicles since 1995. Japan also performs very well relative to the world average for electrical equipment (1.66). However, the LQ for that sector shows a decline from 1.90 in 1995. That is a decrease of 12 percent over the period between 1995 and 2020. Additionally, Japan once performed very well relative to the world average in 1995 for computer, electronic, and optical products, with an LQ of 1.49. However, between 1995 and 2020, Japan's LQ for that industry fell 41 percent to only 0.88. Pharmaceuticals (-12 percent) and fabricated metals (-10 percent) are other industries where Japan used to perform better relative to the world average but is now performing worse. Chemicals (0.95) and

IT and information services (1.03) are relatively close to the global average. (See table 2.)

Overall, Japan's LQ for all industries, measured by the Hamilton Index, was 1.21 in 2020. (See Figure 6.3.) In other words, Japan had 21 percentage points more advanced production than the global economy relative to Japan's GDP. However, that represents a decrease of 7 percent from an LQ of 1.30 in 1995. That change is primarily attributable to the significant declines in the LQs for computers and electronics (-41 percent) and for other transportation (-24 percent). Table 1 also displays these figures. Using the original 2022 Hamilton Index, which excludes chemicals, basic metals, and fabricated metals, the overall LQ for the remaining advanced industries was 1.28 in 2020. That is down from an LQ of 1.40 in 1995. (See table 3.)

Three other industries saw an increase in their global location quotient between 1995 and 2020. Specifically, those industries were motor vehicles (+27 percent); machinery and equipment (+22 percent); and IT and information services (+7 percent). However, that overall increase was concentrated during the early period of 1995-2007. More recently between 2017 and 2020, the LQs for those industries decreased by 3 percent, 10 percent, and 6 percent respectively.

Table 6.1. **Global market shares for Japan, 1995-2020**[55]

Industry	Share in 1995	Share in 2020	% Change 1995-2020
Pharmaceuticals	18.35%	5.36%	-71%
Electrical Equipment	33.88%	9.85%	-71%
Machinery and Equipment	28.83%	11.64%	-60%
Motor Vehicles	23.92%	10.04%	-58%
Other Transportation	16.10%	4.04%	-75%
Computers and Electronics	26.62%	5.22%	-80%
IT and Information Services	17.24%	6.10%	-65%
Chemicals	16.99%	5.60%	-67%
Basic Metals	24.95%	7.55%	-70%
Fabricated Metals	18.25%	5.46%	-70%
Hamilton Index	**23.22%**	**7.16%**	**-69%**

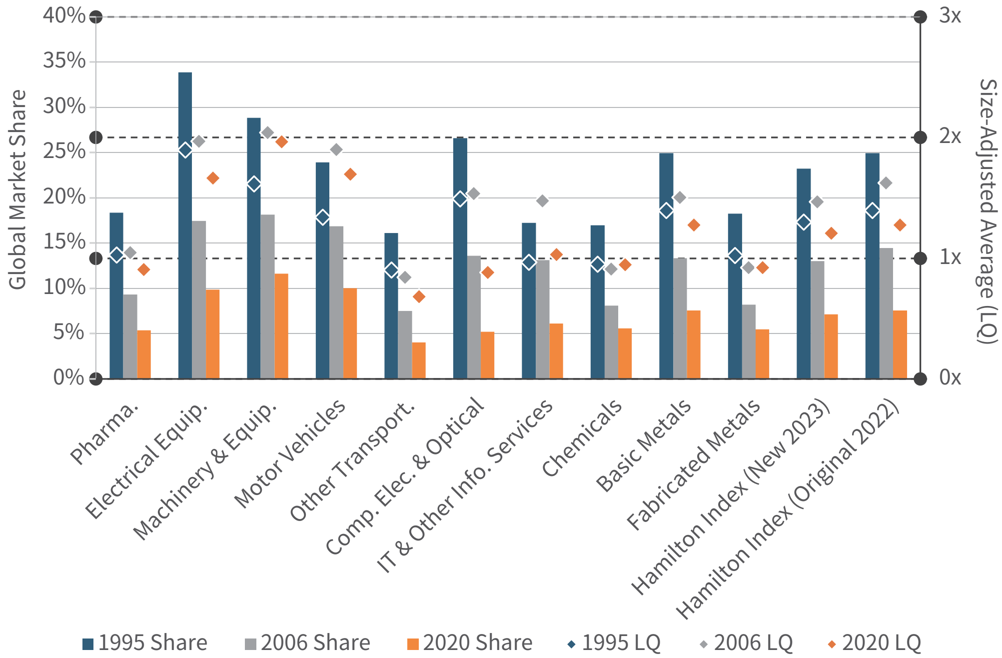
Table 6.2. Location quotient for Japan (new 2023 Hamilton Index)[56]

Industry	LQ in 1995	LQ in 2020	% Change 1995-2020
Pharmaceuticals	1.03x	0.91x	-12%
Electrical Equipment	1.90x	1.66x	-12%
Machinery and Equipment	1.61x	1.96x	22%
Motor Vehicles	1.34x	1.69x	27%
Other Transportation	0.90x	0.68x	-24%
Computers and Electronics	1.49x	0.88x	-41%
IT and Information Services	0.97x	1.03x	7%
Chemicals	0.95x	0.95x	0%
Basic Metals	1.40x	1.27x	-9%
Fabricated Metals	1.02x	0.92x	-10%
Hamilton Index	**1.30x**	**1.21x**	**-7%**

Table 6.3. Location quotient for Japan (original 2022 Hamilton Index)[57]

Industry	LQ in 1995	LQ in 2020	% Change 1995-2020
Pharmaceuticals	1.03x	0.91x	-12%
Electrical Equipment	1.90x	1.66x	-12%
Machinery and Equipment	1.61x	1.96x	22%
Motor Vehicles	1.34x	1.69x	27%
Other Transportation	0.90x	0.68x	-24%
Computers and Electronics	1.49x	0.88x	-41%
IT and Information Services	0.97x	1.03x	7%
Hamilton Index	**1.40x**	**1.28x**	**-9%**

Figure 6.3. **Japan's performance in advanced industries comprising ITIF's Hamilton Index**[58]



5. Major Innovation Challenges

Japan faces several major innovation challenges, including low productivity and weak entrepreneurship rates.

5.1. Japan's Productivity Challenge

In traded sectors, particularly manufacturing, Japan is very much a leader in productivity. This stems in part from Japan's leadership in robotics, with 45 percent of all industrial robots being manufactured in Japan.[59] This has had a spillover effect on Japan's other manufacturing industries. ITIF has previously noted that Japan stands at the front of the pack in robot adoption, with the International Robot Federation (IRF) finding in 2020 that Japan had 390 robots in manufacturing per 10,000 persons, compared to 255 per 10,000 persons in the United States.[60] The government has sought to incentivize upgrades in production technology, with the ultimate aim of improving the country's supply chains. In particular, in its 2023-2024 budget, the government allocated over $39 billion in support for manufacturing industries it deems critical, such as those for semiconductors, electric vehicles (EVs), and medical equipment.[61]

As noted, a key objective of Japan's 2023 Innovation Strategy is bolstering productivity, which has long stagnated in the country. In fact, since 1970, Japan has recorded the lowest productivity of the Group of Seven (G7) nations every single year.[62] And Japan's productivity has been slipping compared to leading global peers: in 2000, Japan's productivity stood at about 70 percent that of the United States, but the level then slipped to around 65 percent by 2010 and to just 60 percent in recent years.[63] By 2020, Japan ranked 23rd for labor productivity among the (then-36) nations of the OECD, its lowest ranking since 1970.[64]

Essentially, Japan's productivity challenge stems from its "dual economy" structure: featuring a highly productive manufacturing/industrial sector, as noted above, but highly unproductive domestic services and non-manufacturing sectors that account for the preponderance of the country's GDP. In fact, from 2000 to 2017, Japanese manufacturing sector workers' value added produced per hour increased from about 4,000 ($36.84) to about 5,800 Japanese yen ($53.42); but non-manufacturing sector workers' value added per hour stayed absolutely flat at about 4,600 Japanese yen (USD42.37).[65]

One challenge is that the Japanese labor force is still "psychologically connected to concepts of lifetime employment."[66] Connected to this is the seniority wage (*nenko*) system that explicitly ties compensation and advancement to length of employment.[67] In addition, regulatory barriers make it difficult for new competitors to challenge incumbents in certain sectors, and moreover, Japan's services sectors have generally been shielded from international competition (unlike their manufacturing firms, which must compete in global markets). As such, the impulse that competition engenders to drive innovation and productivity enhancements is lacking, explaining why Japanese services firms haven't invested in new technologies anywhere near the rate their manufacturing firms have.

Moreover, as Matsumoto notes, "Japan's long-standing lifetime employment model has also contributed to a certain degree of stasis."[68] While the legal strictures around lifetime employment have mostly been removed—making the labor market more flexible in theory—downsizing is viewed negatively and workers themselves "are reluctant to advance their careers by changing employers, which limits their incentive to develop new skills."[69] One way Japan has tried to address its labor marker challenge has been by permitting firms to hire non-regular (temporary) workers or *haken*. Such workers, which accounted for one-third of Japan's workforce by 2013, may account for as much as half as 2050, but because they're officially temporary workers, they have few incentives to excel, and employers aren't incented to invest in their skills, so this further dampens productivity.

5.2. Weak Industry-University Linkages

One recurrent theme over the past several decades has been the weak state of Japan's industry-university linkages, which have inhibited innovation in Japan.[70] As Sean Connell wrote for a 2018 National Bureau of Asian Research report on Japan's innovation system, "Collaboration between universities, research institutions, and the private sector in Japan is limited."[71] Toshio Fujimoto of Takeda Pharmaceutical further explains that "the opportunity to change careers between sectors (academia-industry-public-venture capital) is very limited in Japan."[72] Weak government funding for research, inadequate translational research capacity and interest (a strong focus on theoretical and abstract education), and weak linkages between universities and risk-capital communities have all contributed to this dynamic.

As Kazuyuki Motohashi wrote in an OECD report exploring Japan's national innovation system, "The Japanese innovation system is seemingly characterized by the 'in-house development principle' mainly adopted for innovations in larger companies, and differs distinctly from the network-type innovation system found in the United States, which tends to involve venture companies and universities as well."[73] Indeed, In contrast to other nations, innovation by large Japanese firms relies less on contracted public research and international collaboration than on innovation within the corporate group. Challenges Motohashi cites here include "the low mobility of researchers in companies and universities, the short supply of venture capital for start-up companies, the tendency of universities to focus on basic research and to be unenthusiastic about industry-university cooperation, and a corporate climate in which in-house development is highly valued and strategies of alliances disregarded."[74]

Indeed, weak industry-university linkages have long been a challenge for Japan's broader innovation system. For instance, Japan significantly lags behind international peers in average industry funding per academic worker, with an average level of just $5,125, about one-sixth the approximately $30,000 amount it is for leaders Germany and South Korea. (See Figure 6.4.) This dynamic is also visible in Japan's very weak university share of corporate R&D funding, which stood at only 2.8 percent in 2019, well below the 14.3 and 13.6 percent levels of peers in South Korea and Germany, respectively. (See Figure 6.5.) Japan has long trailed the United States in industry-university R&D investment levels as a share of GDP, with the United States on average investing 1.75 times Japan's amount over the period from 1981 to 2019. (See Figure 6.6)

To be sure, Japan has long recognized this challenge. To its credit, in 1998, the country introduced the Law for Promotion of University-Industry Technology Transfer, which supports the launch of technology-licensing offices at universities and other public research institutions.[75] Moreover, the following year, Japan introduced its version of the United States' critically instrumental Bayh-Dole Act, which permits universities ownership of intellectual property stemming from federally funded research.[76] In 2000, Japan's Industrial Technology Enhancement Act made further refinements, including allowing university faculty members to also become corporate officers. In 2004, Japan's national universities acquired the status of national university corporations, which afforded them increased autonomy and encouraged revenue generation through industry cooperation and entrepreneurship.[77] As was America's experience with the Bayh-Dole Act, which turbocharged American universities as engines of innovation, Japan's legislation spurred the development of technology transfer capacities at Japanese universities. A survey by the University Network for Innovation and Technology Transfer (UNITT) finds that, by 2016, Japanese universities, research institutes, and technology licensing offices had hired about 1,000 specialists in tech transfer, joint research, and venture support. That year alone saw more than 6,000 patent filings and close to 3,000 licensing agreements, while over the previous decade, Japanese university income from royalties had tripled.[78]

Figure 6.4. Average industry funding per academic researcher (2019, or the latest year available)[79]

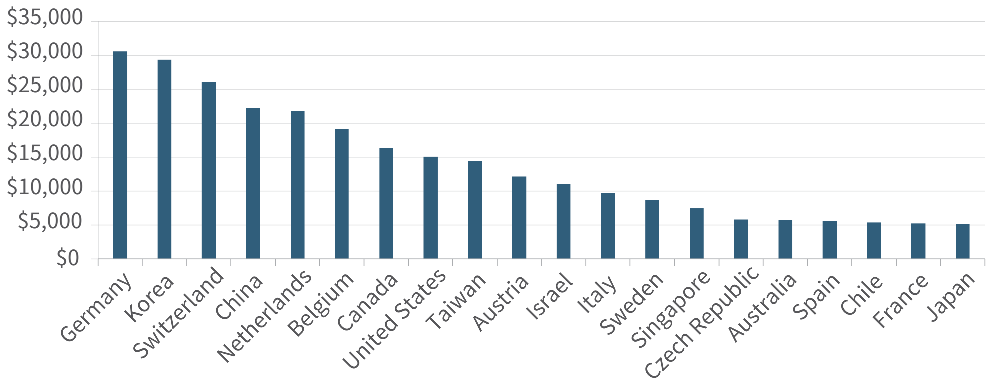


Figure 6.5. University R&D funded by business enterprises, as share of total university R&D, 1995–2019[80]

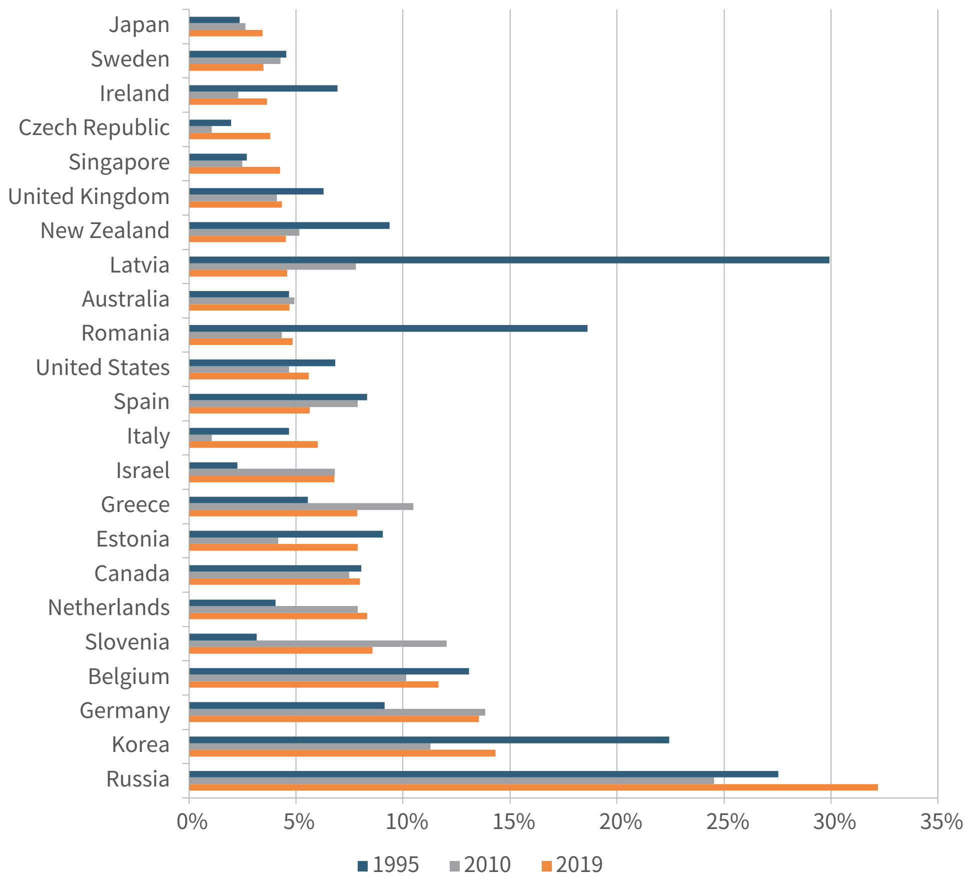
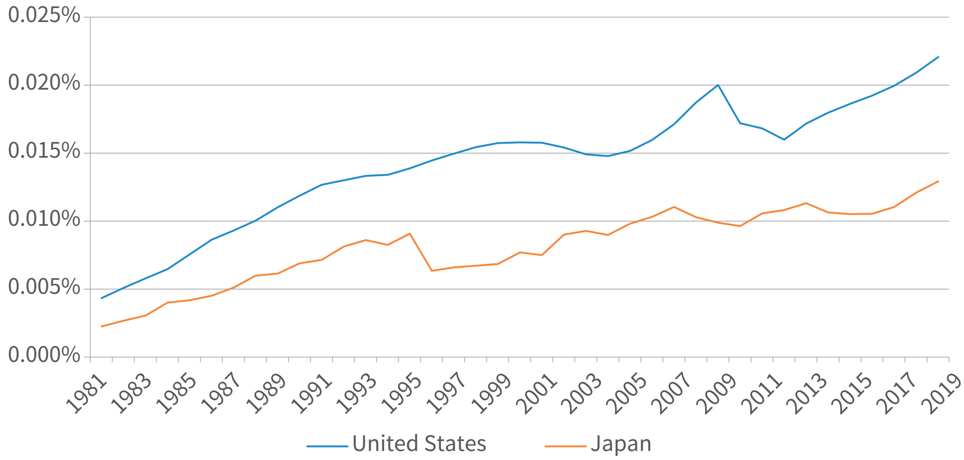


Figure 6.6. **Industry-university R&D investment, as a share of GDP, 1981–2019**[81]



But while Japan has certainly improved its policy environment supporting industry-university collaborations, more significant institutional, organizational, and cultural challenges continue to impede such exchanges. Indeed, Hiroaki Suga, a chemist at the University of Tokyo who co-founded the $5 billion biotech start-up PeptiDream, explained that "a large part of the problem is the old-fashioned view among professors that commercialization efforts will taint the quality of their academic work … Researchers engaged in industrial applications are less respected than those involved in basic science."[82]

Overall, just 3.9 percent of new university-developed technologies in Japan get licensed to start-ups each year, well below the 17.1 percent rate in the United States.[83] This means Japan's universities aren't producing sufficient feedstock to support entrepreneurial innovation in Japan. As noted, Japan has tried to bolster its levels of university R&D funding with the $88 billion University Fund, but it remains to be seen to what extent the initiative bears fruit.

5.3. Weak Entrepreneurship

Japan has long struggled with low entrepreneurship rates. As one observer writes, "To revitalize its sluggish economy, Japan must create incentives to promote homegrown start-ups and must rapidly commercialize patented, cutting-edge technologies."[84] Indeed, entrepreneurial startups that scale are a vital component of countries' economic and employment revitalization. For instance, Kyoji Fukao of Hitotsubashi University and Hyeog Ug Kwon of Nihon University found that Japanese companies founded after 1996 contributed a net positive of 1.2 million new Japanese jobs, whereas older companies shed a net 3.1 million jobs.[85]

Yet, as the National Bureau of Asian Research writes, "Japan is largely perceived as a challenging place for entrepreneurs to launch successful businesses."[86] Japan's "organization man" culture stunts entrepreneurship and new firm creation. In fact, one 2018 study ranked Japan as the world's fourth-least entrepreneurial country.[87] A Global Entrepreneurship Monitor study found that 4.9 percent of U.S. adults between the ages of 18 and 64 are working actively to establish new businesses, compared to only 1.9 percent in Japan.[88] And the OECD finds that, among its member countries, Japan ranks last in the average annual entry rate of new enterprises, with a rate barely one-third that of the United States.[89]

The amount of venture (or risk) capital available to support start-ups in Japan is a fraction of that available in peer countries. For instance, total investments in Japan's startups in 2022 reached 877 billion yen ($6.7 billion).[90] However, that amount pales compared to the $238 billion in venture capital invested in the United States in 2022 (that figure is down considerably from the $345 billion invested in 2021), even considering the fact that Japan's GDP is one-sixth the size that of the United States.[91] Japan's level of VC investment was also considerably lower than the $69.5 billion invested in China in 2022.[92] South Korea recorded 6.8 trillion won (about $5 billion), in VC investment in 2022, slightly less than Japan's level (although South Korea's economy is 40 percent the size of Japan's).[93]

Japan's entrepreneurship gap has been attributed to a variety of cultural, societal, educational, legal, and financial factors.[94] For instance, culturally, 55 percent of potential Japanese entrepreneurs admitted in a 2015 World Values Survey that they were afraid of failure, the second-highest rate in the world.[95] One Global Entrepreneurship Monitor found that Japan, followed by South Korea, had the fewest citizens who saw opportunities in entrepreneurship and that the country ranked last in the proportion of people interested in entrepreneurship as a career.[96] Socially, as Toshiko Oka, the CEO and founder of Abeam M&A Consulting Ltd., explains, "the status of entrepreneurs in Japan is not high, particularly relative to their counterparts in the U.S."[97] In part this is because Japan remains a country in which failure is generally not accepted and large risks are avoided. As such, few people are willing to take the risks associated with starting a technology company or funding a nascent technology start-up. What venture capital funds do exist in Japan are therefore almost universally attached to large companies, which tend to be more risk-averse, and Japan lacks the founder-investor community that helps technology start-ups grow (through funding, mentorship, and networking) and is needed to create a self-sufficient start-up ecosystem where the successful founders of the past help create successful founders in the present and future, such as in Silicon Valley, Taiwan, and Israel. Moreover, Japan's national aversion to risk makes it less willing to adopt and implement technologies until their social and economic effects are fully known. Risk aversion thus harms both the supply of and demand for emerging technologies in Japan.

Scholars also note that the lack of limited legal liability and outdated bankruptcy laws are barriers to entrepreneurship in Japan. For instance, if a start-up receives debt financing, the assets of both the company and the individual are collateralized, Moreover, debt is transferable, such that if the start-up fails, the founder's guarantor or family assumes responsibility for the unpaid debt (and even if the founder perishes, the family remains liable for the debt).[98] Tomoko Inaba, a former AIG Director, adds that "[the] typical Japanese parent often does not support his or her child's aspiration of becoming an entrepreneur."[99]

To be sure, Japan's entrepreneurial environment has improved in recent years. The country now boasts 20 unicorns, including Rakuten, Gokin Solar, Preferred Networks, and Playco.[100] And there are many more innovation incubators and accelerators operating in Japan today, including IMPACT Japan, Startup Weekend, Open Network Lab (an incubator resembling U.S.-based Y Combinator), EGG Japan, Souzei Village, and MOV Lounge.[101] So Japan is making progress in entrepreneurship, but the country has a considerable way to go in this department.

5.4. Weak Internationalization

A related factor relates to internationalization. Japan's relative seclusion from the international research community is at least exacerbated by its low English-speaking rate. English remains the international language of science, and an inability to speak it and participate in the international research community hinders both the country's scientific and technological development and its ability to attract international talent (which further reinforces the harm to Japan's scientific and technological development).

5.5. Aging Population

Japan's potential labor force—those between ages 15 and 64 as a share of the total population—peaked in 1991–93 at just under 70 percent; since that time, however, Japan's potential labor force has fallen quickly to just above 59 percent, the lowest level among Group of Seven countries.[102] As Gee Hee Hong and Todd Schneider at the International Monetary Fund write, Japan's "older and smaller population has implications for productivity and long-term economic growth;" however, these need not necessarily be negative.[103] As they write:

Older workers may enjoy higher productivity because they accumulate work experience, while younger workers benefit from better health, higher processing speed, and the ability to adjust to rapid technological changes and greater entrepreneurship, leading to more innovation. These two counterforces suggest an inverted U-shaped relationship between age and productivity, with productivity lowest at the beginning and ending phases of a career.[104]

However, they note this effect is counterbalanced by the reality that an aging society will "likely increase the relative demand for services (e.g., health care), causing a sectoral shift toward the more labor-intensive—and less productive—service sector."[105] Increasing the application of "automation, artificial intelligence, and robotics (including technology to increase productivity per worker)" will therefore be crucial to addressing Japan's demographic changes.[106] Japan's aging society will certainly bring structural changes and challenges, but these needn't necessarily be solely determinative of the competitiveness of

Japan's economy or industries in the years ahead: the question is whether Japan can adopt the technologies needed to bolster productivity and output in the face of a shrinking population.

As an October 2023 Goldman Sachs report writes, "For three decades, Japan's economy stayed stagnant, plagued by a combination of low growth, low inflation, and low interest rates. The term "Japanification" became shorthand for the country's prolonged economic plight." But, the report continues to note that, "Japan's economy is experiencing a revival in 2023, spurred by domestic macroeconomic strength, a departure from deflation, and corporate governance reform." In short, "Japan finds itself in a domestic demand recovery characterized by an unfamiliar yet desirable cycle of rising prices and wage growth."[107] As the report's authors conclude, whether this persists will depend on "whether consumer and corporate activity changes in line with a shift from a deflationary to an inflationary mindset" and whether geopolitical tensions don't significantly disrupt the existing nature of global trade flows in industries so critical to Japan's economy, such as semiconductors and autos.[108] In other words, Japan's economy appears to have its best shot in decades to achieve a "steady state," but it's not quite there yet.

6. Conclusion

Ultimately, Japan has created "an innovation ecosystem that reflects government priorities, chosen because they are perceived to be necessary for future growth and global technological leadership."[109] Japan's NIS is marked by significant government guidance and close connections with industrial leaders. The approach has historically borne fruit for Japan, but today Japan's industrial competitiveness is sliding, its productivity is languishing, and entrepreneurship is stagnating. Japan has strengths but needs to reimage its innovation strategies for the 21st-century digital economy.

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Chapter 7

Taiwan

Stephen EZELL

Taiwan boasts a sophisticated, evolving national innovation system, grounded in a whole-of-government approach where government officials charged with promoting national innovation and technology competitiveness have considerable tech policy experience and knowledge. Overall, having mastered the process of catching up technologically with the West, Taiwan is seeking to move from a fast follower to a global leader. The country's government and business leadership are critically aware of the nation's intense global techno-economic competition. And innovation is not just a priority for the central government, but also for local governments.

1. Taiwan's Advanced Industry Performance

Taiwan has boasted a higher LQ than China since 1995. Furthermore, the divergence between Taiwan's and China's performance has grown. Between 1995 and 2020, China's overall LQ increased from 1.41 to 1.47, while Taiwan's overall LQ increased from 1.72 to 2.10, the highest in the world.

In terms of industry strength, Taiwan is above average in most industries except for motor vehicles, IT and information services, and pharmaceuticals. (See Figure 7.2)

Figure 7.1. **Hamilton Index industries' shares of Taiwan's economy**

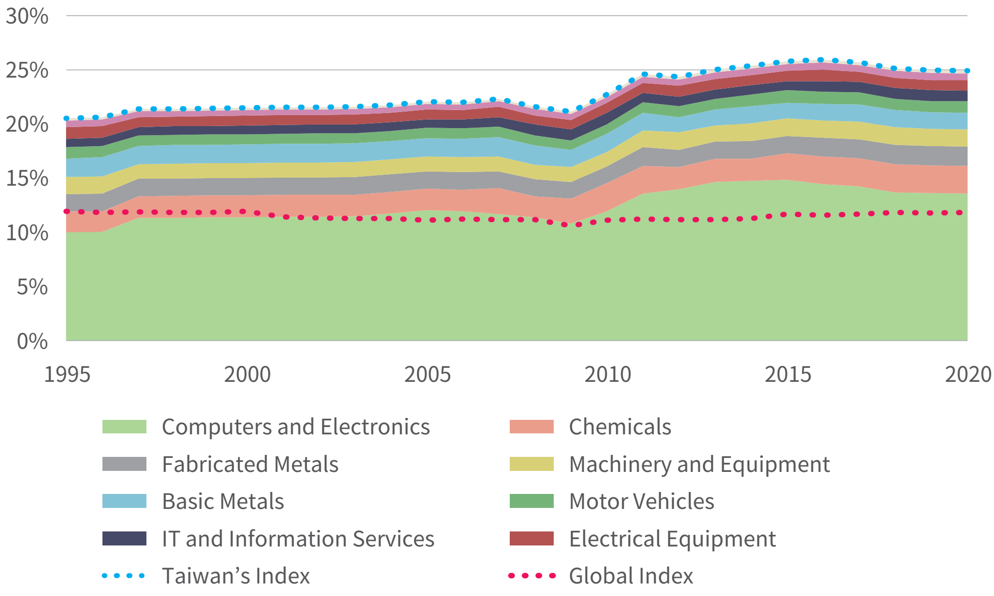
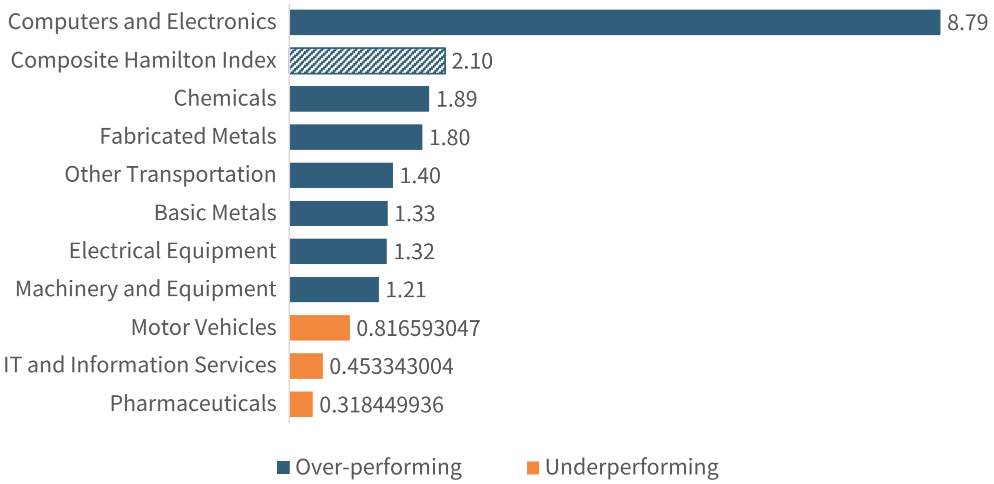
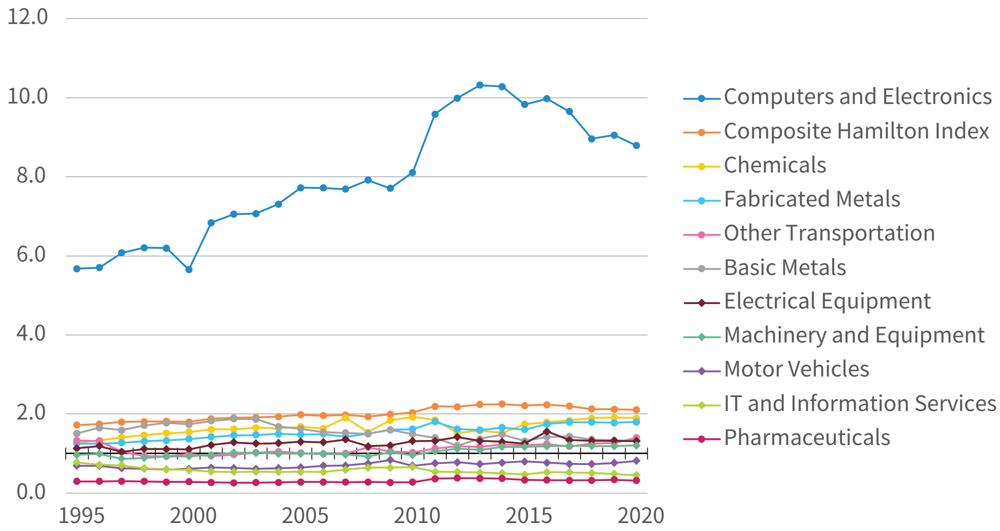


Figure 7.2. **Taiwan's relative performance in Hamilton Index industries (2020 LQ)**



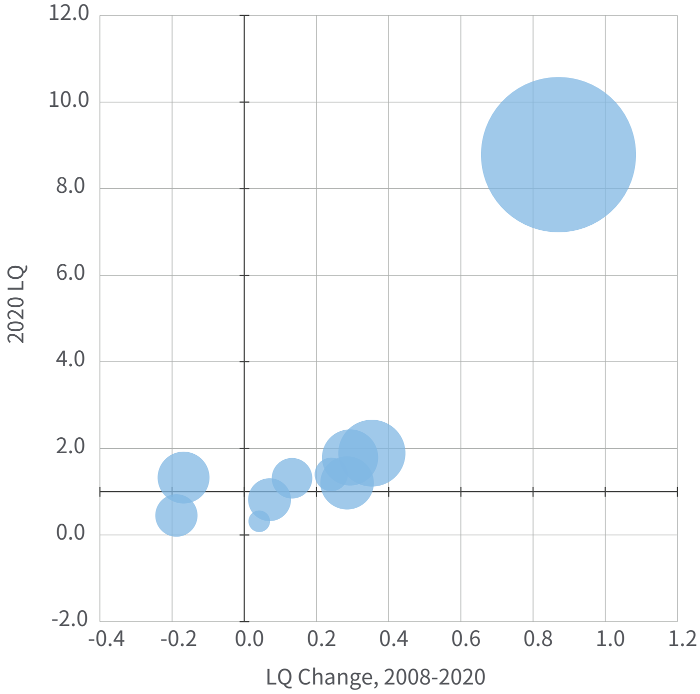
Due to the presence of TSMC, Taiwan's strongest industry is computers and electronics, where it has an extremely high LQ of 8.79. It is also strong in chemicals, fabricated metals, other transportation, basic metals, electrical equipment, and machinery and equipment. In contrast, Taiwan's worst-performing industry is pharmaceuticals, with an LQ of only 0.32.

Figure 7.3. Taiwan's relative historical performance in Hamilton industries (LQ trends)



Taiwan has six industries in the "strong, growers" quadrant. Of those, computers and electronics have improved the most. Other industries in that quadrant are electrical equipment, other transportation, machinery and equipment, fabricated metals, and chemicals. It has two industries in the "weak, growers" quadrant, pharmaceuticals and motor vehicles. The IT and information services industry is in the "weak, declining" quadrant. Basic metals is the only industry in the "weak, decliners" category. This is not to say that the industry is not growing, but rather, that it is not growing as fast as the overall Taiwanese economy. Taiwan's momentum score is far ahead of any other nation's (1,503), 13 times that of the United States. Most of this stems from Taiwan's truly outstanding growth in computers and semiconductors. However, given global tensions and concerns over China's future actions regarding Taiwan that have spurred reshoring activities such as the U.S. CHIPS Act, it's unlikely that this sector will continue to enjoy the growth rates it has in past years.

Figure 7.4. **Taiwan's net performance in Hamilton industries since 2008 (scaled to 2020 output)**



2. Taiwan's Key Innovation Inputs

Countries' levels of R&D investment and the extent of the scientific workforce represent critical enablers of their national innovation capacity. Taiwan's national R&D intensity (R&D as a share of GDP) steadily increased over the past decade, increasing from 2.82 percent in 2010 to 3.78 percent in 2021, an increase of over one-third over that period. (See Figure 7.5) Taiwan now boasts the world's third-highest national R&D intensity, behind only Israel (5.56 percent) and Korea (4.93 percent). While that's certainly positive, a concern is that the private sector is increasingly the source of that R&D investment, while the government share has retrenched. In fact, the Taiwanese government's share of the country's R&D expenditures has declined from 51 percent in 1991 to just 19 percent today, a decline of almost two-thirds. (See Figure 7.6)

Figure 7.5. Taiwan's national R&D intensity, 2010–2021[1]

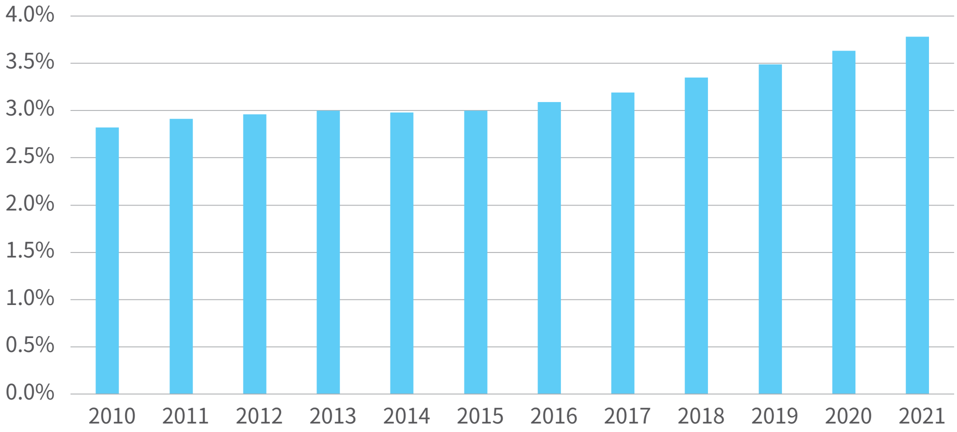
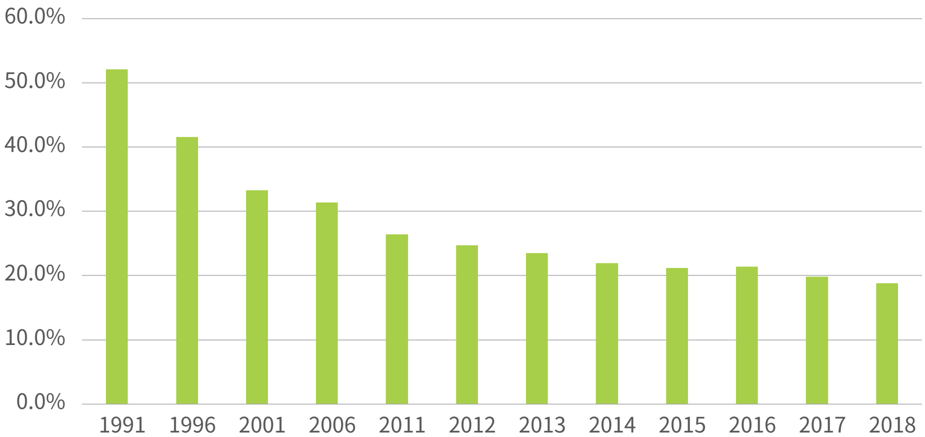


Figure 7.6. Taiwan's government R&D expenditure as a percentage of total R&D expenditure, 1991-2017[2]

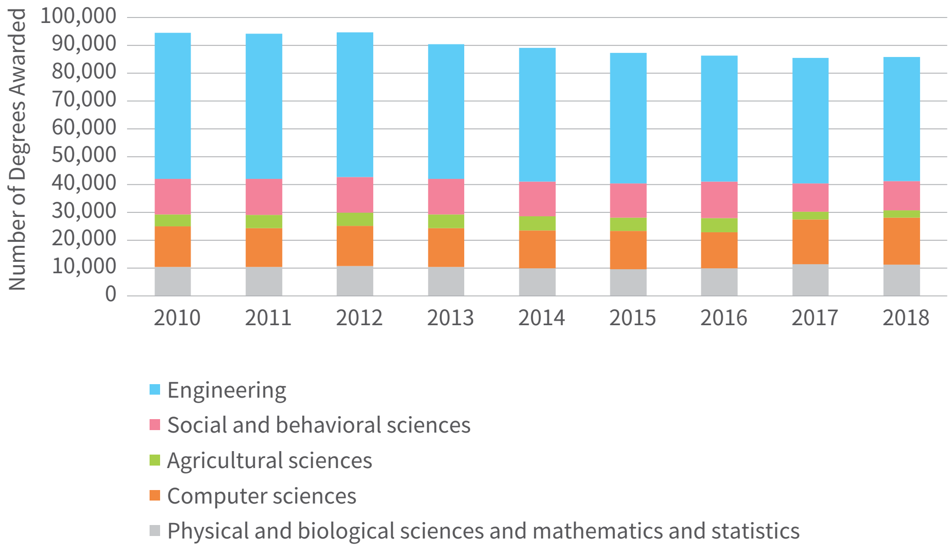


One driving factor behind Taiwan's economic and technological development has been its focus on advancing its education system. Part of this advancement has meant expanding the opportunity for postsecondary education, and Taiwan now has 152 universities, colleges, and junior colleges despite having a population of only 23 million, giving it one of the highest higher-education densities in the world.[3] Taiwan's technical universities are also playing an expanded role as incubators for start-ups and business ventures developed by faculty and students. In Taiwan, there are currently 98 college-level institutions with innovation incubators (despite there being only 152 universities, colleges, and junior colleges).[4]

Taiwan has become a world leader in producing science and engineering (S&E) graduates, many of whom would emigrate to the United States for graduate school and work in Silicon Valley, only to return to Taiwan with their acquired knowledge and connections to start businesses. In 2010, 42 percent of first-university degrees awarded in Taiwan were in S&E fields. This was greater than the share in Germany (39 percent), South Korea (41 percent), or the United States (38 percent). However, a concern for Taiwan is that it is producing fewer scientists and engineers than it did in the past. From 2010 to 2018, the number of science and engineering first university degrees in Taiwan declined by nearly 10,000 students (from 94,431 to 85,718), a nearly 9 percent decrease.[5] (See Figure 7.7)

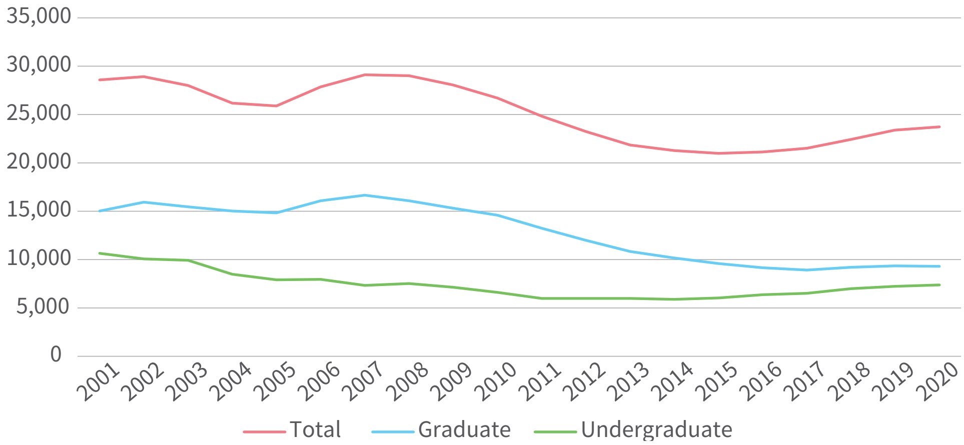
Moreover, the share of all first degrees being awarded in S&E fields fell to 37 percent from 2010 to 2018. While still higher than the shares in other high-income countries, this share is now lower than in Germany (40 percent), South Korea (40 percent), and the United States (41 percent). The case is even more concerning for S&E doctoral degrees. Between 2010 and 2018, the number of such degrees awarded dropped from 2,500 to 1,900 (a 24 percent drop), and such degrees as a share of total doctoral degrees awarded dropped from 68 percent to 57 percent.

Figure 7.7. Taiwan S&E first university degrees, by selected region, country, or economy and field, 2010–2018[6]



A related concern is that the number of Taiwanese graduate students studying in the United States decreased from 15,022 in 2001 to 9,315 in 2020, a decline of approximately 40 percent. (See Figure 7.8) Policymakers from both nations should recognize the importance of the circulation of high-skill talent between the two countries and prioritize greater levels of STEM education exchange. It's been estimated that over 50 percent of CEOs of Taiwanese companies studied in the United States at some point, so increasing STEM student linkages and exchanges between Taiwan and the United States offers potentially tremendous benefits going forward. These connections make it easier for Taiwan to engage in partnership with American technology companies.

Figure 7.8. Number of Taiwanese STEM students studying in the United States, 2001-2020[7]



3. History and Evolution of Taiwan's NIS

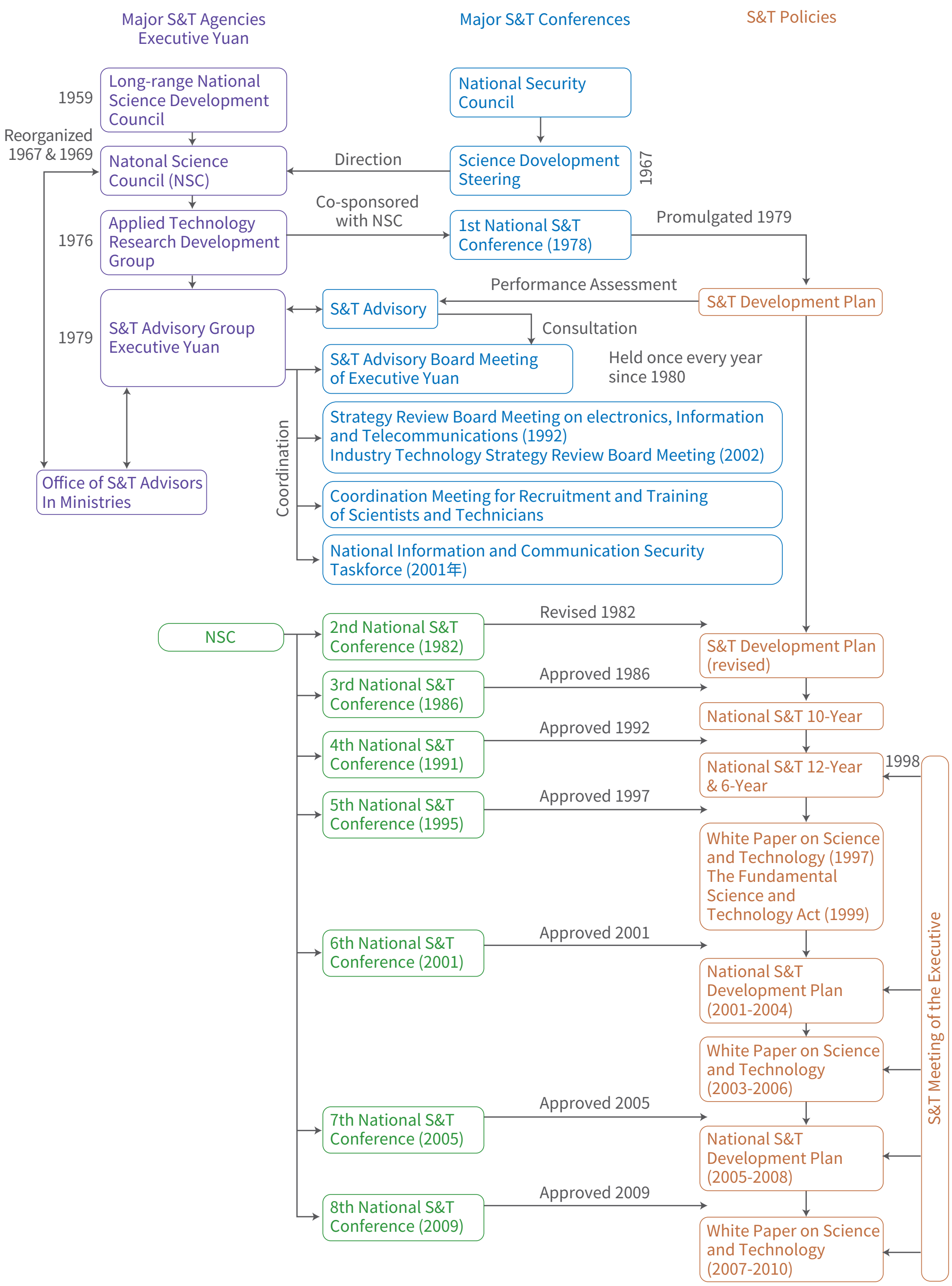
In 1959, Taiwan established the "Long-range National Science Development Council," the first Taiwanese government agency involved in actively promoting scientific development, it focused on pressing topics such as increasing the production of agricultural products. Over the ensuing decade, Taiwan focused on setting up export-processing zones, focusing on labor-intensive industries, and establishing an export-oriented manufacturing sector.[8] By 1967, Taiwan set up a Science Development Steering Committee under the National Security Council, and in 1969 it stood up the National Science Council (NSC), which began to develop a series of four-year National Scientific Development Plans, with the first arriving in 1968 (with additional plans released in 1972 and 1976). A National S&T Development fund was established in 1969 to invest in science and technology (S&T) R&D, build facilities and capabilities, and attract talent.[9] As of 1969, the NSC became the highest-level government agency responsible for setting the path for Taiwanese S&T policies.

Taiwan held its first National S&T conference in 1978, a second in 1982, and in 1986 it held the Third National S&T conference, which importantly drafted a 12-year Long-term National S&T Development Plan (that was to be implemented from 1991 through to 2002). In 1996, the Fifth National S&T Conference announced concrete proposals and budgets for new programs in high-tech industrial development, advanced technological research, and balancing science and the humanities.

In 1999, Taiwan enacted the fundamental S&T Act, which set guidelines and principles for the promotion of Taiwanese S&T and economic development. The NSC published National S&T Development Plans (2001-2004 and 2005-2008) and a series of White Papers on S&T (2003-2006 and 2007-2010), each laying out the current status, visions, and strategies for S&T development in Taiwan. Figure 7.9 shows the development of Taiwan's S&T system and policy development from 1959 through 2009.

As this series of case studies has shown (and notably with Japan), heavily government-directed industrial strategies have tended to help the Asian tigers catch up to the global production frontier. However, then the challenge is whether a country's enterprises and industries have truly developed the real innovation capabilities needed to sustainably innovate, and also whether government entities can adapt their models to not just emulate the previous successes of other nations' industries, but also adapt in their own innovation policymaking to enable new innovative companies and sectors to flourish (and existing ones to adapt).

Figure 7.9. The Timeline of Taiwan's S&T System and Policy Development[10]

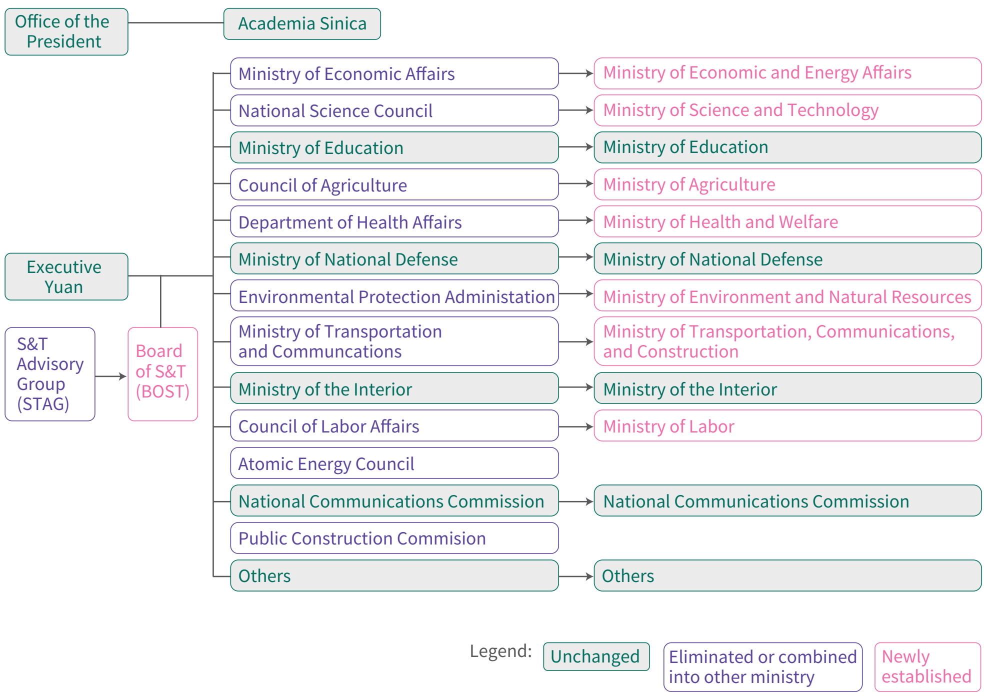


A 2009 paper by Mark Dodgson, which analyzed the development of Taiwan's NIS over the previous two decades, concluded that Taiwan had managed to meet that challenge, at least up to that time. As he wrote, Taiwan:

> Showed significant efforts to shift beyond a very successful past model of innovation based on technological learning and catch up with the world's best practices. New institutional forms are emerging in Taiwan: more basic research, a greater focus on intellectual property protection, new models of collaboration, a new venture capital industry, and new corporate behaviors, such as spinouts.[11]

In January 2012, Taiwan underwent a major reorganization of the leading actors and agencies guiding its science and technology system, as shown in Figure 7.10.

Figure 7.10. 2012 Reorganization of Taiwan's S&T Structure[12]



Thus, Taiwan's government has long identified a set of emerging and critical technologies for increased government support. There is virtually no ideological resistance to "picking winners" as there is in Anglo-Saxon nations. The government is trusted to identify state interests in technology innovation and advance them, albeit in close partnership with the private sector, which leads. In this sense, there is a widespread consensus that a national interest exists, something that is more than the aggregation of disparate and often conflicting interests.

As discussed below, ITRI reflects this consensus. There the government provides considerable funds for a research institute focused on key technologies with a mission to work with industry and entrepreneurs. For example, on a per-capita basis, ITRI employs 60 percent more people than the entire U.S. Department of Energy lab system. The principal job here is to help identify emerging technology areas where Taiwan could be competitive and do the groundwork to enable the private sector to succeed internationally. The government also plays a facilitating and supportive role in fostering a higher-performing innovation system. It facilitates connections between suppliers, original equipment manufacturers (OEMs), universities, and national research centers. Moreover, Taiwan invests considerable funds into techno-economic development, especially through the National Development Fund.[13]

In this regard, business associations, such as the Taiwan Electrical and Electronic Manufacturers Association, play a more active role than trade associations in the West which largely focus on lobbying for member interests. In Taiwan, these associations conduct studies and analyses and meet annually to develop recommendations for the Ministry of Economic Affairs. There are also sectorally based government-sponsored research institutes and networks in an array of industries. In this sense, the system is more "corporatist" than the U.S. system, which is grounded in interest-group liberalism. Emblematic of this is that the government holds a seat on the board of TSMC, something that would likely never happen in the United States. As such, unlike in the United States where the idea of "what is good for GM is good for the United States" is seen as anachronistic and naïve, there is a broader consensus in Taiwan that what's good for TSMC is good for Taiwan and vice versa. As such, there appears to be more formal cooperation and learning between industry and government and attempts to develop consensus.

Taiwan still feels pressure to innovate, partly because as Mark Zachary Taylor noted in his book *The Politics of Innovation: Why Some Countries Are Better at Science and Technology*, because of resource constraints and of course, the looming challenge from China. However, as Taiwan has moved from being "hungry" and needing to develop and catch up, success now risks breeding complacency. In recent years, some projects—such as developing new factories—have faced opposition from the environmental community. As such, a key question for Taiwan going forward is whether can it "stay hungry." Today, many people in Taiwan are aware of and proud of Taiwan's technological success. But will voters take this success for granted?

Looking forward there are several key issues at stake. First, how easily can Taiwan transition from the older model of "catch up" to a new model of global innovation leader. The tasks are quite different, including creating an education system that supports critical thinking and a culture of entrepreneurship. To be sure, compared to China, Taiwan is more open and people are more free to think and act, and this helps stimulate innovation. In part, this was because the generation that moved to Formosa in 1949 were risk-takers. There is concern that the current generation is less "scrappy" and hungry.

4. Architecture and Organization of Taiwan's National Innovation System

Today, Taiwan's National Science and Technology Council (NSTC, a descendent of the aforementioned NSC) has overall responsibility for the articulation and organization of Taiwan's national innovation system (NIS), innovation strategy, and innovation policy. In particular, NSTC directs the promotion and funding of academic research and development of Taiwan's network of science and technology and science parks. Key departments within NSTC include the Department of Planning, Department of Foresight and Innovation Policies, Department of International Cooperation and Science Educations, Department of Engineering and Technologies, and Department of Life Sciences.

In terms of operationalizing Taiwan's NIS, much of the responsibility falls to the Ministry of Economic Affairs (MOEA). MOEA is a cabinet-level agency responsible for formulating policies and laws for industry and trade, foreign direct investment, energy, minerals, measurement standards, intellectual property (IP), and state-owned enterprises. In particular, MOEA contains Taiwan's Department of Industrial Technology (DoIT), whose primary mission is to implement technology development partnerships (TDP) to enhance industrial technology and accelerate the upgrading of industry. DoIT manages three key TDP programs: TDP for Industry, TDP for Academia, and TDP for Non-Profit Organizations.

DoIT's flagship institute is the Industrial Technology Research Institute (ITRI). Founded in 1973, ITRI is a nonprofit research and development (R&D) institute that conducts R&D in applied technologies to advance private-sector growth. (ITRI was formed that year through the merging of the United Industrial Research Institute and Mining Research Institute.) Over the past five decades, ITRI has helped Taiwan establish innovative science and technology industries, assisted traditional industries in technology upgrading, provided training for industrial technology talent, and blazed trails for many advanced and critical industries along Taiwan's journey of industrial development.[14] ITRI has played an instrumental role in transforming Taiwan from a labor-intensive to a high-tech economy and building Taiwan's international economic competitiveness. Many of Taiwan's most successful high-tech companies, including the semiconductor titans Taiwan Semiconductor Manufacturing Corporation (TSMC) and United Microelectronics Corporation (UMC), can trace their origins to ITRI.[15] Other notable spinoffs from ITRI include TSMC in 1987, the Taiwan Mask Corporation (TMC) in 1998, and the Vanguard International Semiconductor Corporation (VIS) in 1994.

Dodgson attributes ITRI's success to its having "developed a successful strategy focused on using innovation networks for technology diffusion."[16] As he elaborates:

> In this model, an international market opportunity is identified by ITRI, which then assembles a network with a combination of several large multinational firms and a number of small Taiwanese firms. Access to the Asian market for multinationals is traded for access to technology. The local part of the alliance is structured to maximize the flow of knowledge to constituent firms, which cooperate to build products based on this technology but also compete to bring these products to market. Over time, two or three dominant firms grow out of

this network, which have the technical and learning skills needed to compete successfully in international markets.[17]

As Dodgson explains, Taiwan followed this approach "in nearly all elements of the information technology developed in Taiwan since the inception of ITRI," and it has continued to evolve.[18] The role of public research institutes in "hastening technology diffusion amongst local firms" with public research institutes (like ITRI) "serv[ing] initially to assimilate advanced technology from overseas and rapidly diffuse them to local enterprises, but increasingly also to serve as the coordinating nodes to promote indigenous technology creation via innovation networks and strategic R&D programs as well."[19]

Historically, ITRI focused on six core technology areas: Information and Communications Technology (ICT); Electronics and Optoelectronics; Materials, Chemicals, and Nanotechnology; Biomedical and Medical Devices; Mechanical and Systems; and Green Energy and Environment. ITRI personnel have played an important role in the development of countless next-generation technologies, including WIMAX wireless broadband, solar cells, radio frequency identification technology (RFID), light electric vehicles, flexible displays, 3-D ICTs, and telecare technologies. Several ITRI labs, including the Flexible Electronics Pilot Lab and the Nanotechnology Lab, provide international-level research platforms where R&D can be conducted jointly with global partners. ITRI also focuses on service innovation—in particular, leveraging ICTs to bolster the competitiveness of Taiwan's services industries.

ITRI's over 6,000 employees have produced more than 15,000 patents, and its personnel produce an average of five new patents every day. Metrics and measures ITRI uses to evaluate its impact include the number of patents granted, licensing income/contracts, the number of spin-off companies, the income generated by industrial and research contract services, and the amount of induced investment through incubation operation.[20]

ITRI very much follows a U.S. Defense Advanced Research Projects Agency (DARPA) model, keying on relatively short-term (i.e., 3-5 year), nimble projects led by an experienced and energetic project manager. Research programs focus on speed and time to market, with the goal of quickly moving technology from Technology Readiness Level (TRL) 4/5 (i.e., initial technology feasibility evaluation in a lab) to TRL 8/9 (i.e., system/technology complete and qualified and then deployed in an operational environment). ITRI works on the development of many advanced technologies which can then be picked up and commercialized by Taiwan's companies across a variety of sectors.

As Taiwan first developed its ICT industry, it relied on collaborations between multinational corporations (MNCs), returning Taiwanese Silicon Valley engineers, and small independent researchers and companies, with ITRI indispensable to facilitating the transfer of knowledge between these parties. A nice example of this is semiconductor technology and the creation of the Electronics Research and Services Organization (ERSO). In 1976, ERSO signed a five-year technology transfer agreement with the Radio Corporation of America (RCA). As part of this agreement, ERSO sent 37 engineers to the United States for one year to be trained in IC design and manufacturing. According to AnnaLee Saxenian: "This team (now known as the RCA-37) formed the core of the leadership of Taiwan's IC industry in subsequent decades."[21] Thanks to this technology transfer program, UMC became the first spin-off of ERSO in 1979, and Robert Tsao, a member of the RCA-37, became its CEO.

By 1994, TSMC had become Taiwan's largest semiconductor manufacturer, pursuing the "fabless" business model. This itself was made possible by "the decoupling of the IC design and fabrication stages [thanks to] the ability to codify knowledge of device characteristics in computer models using CAD technology."[22] TSMC was also assisted by VLSI Technology's decision to transfer specifications for 1.2-micron technology to help TSMC upgrade to that level of process technology.[23] This helped TSMC to by the early 2000s, near catch up with Intel in "being able to produce multiple products with multiple processes within a single fab and in achieving extremely high production yields."[24] Yield remains a foundational challenge for semiconductor manufacturers. Even today, analysts estimate that TSMC's yield rate is 80 percent of its latest chips (and TSMC's one of the best in the world at it).[25]

In 2020, ITRI released its "2030 Technology Strategy and Roadmap," which seeks to enhance the development of intelligentization-enabling technologies and focuses on three specific application domains: Smart Living, Quality Health, and Sustainable Environment.[26] As ITRI President Edwin Lu explained, in launching the 2030 Technology Strategy and Roadmap, ITRI and its stakeholders "examined major macro-environmental factors and envisioned future life scenarios in the next ten years to determine directional statements for our R&D."[27]

Beyond ITRI, Taiwan's NIS is well supported by a deep network of industry clusters centered on several key science technology and software parks distributed around the country. These include especially:

- Hsinchu Science Park, which focuses on integrated circuit (IC) manufacturing, semiconductor material and equipment, and biotechnology;
- Central Taiwan Science Park, which focuses on optoelectronics, semiconductors, and precision machinery;
- Southern Taiwan Science Park, focused on flat displays, optoelectronics, and precision machinery;
- Nangang Software Park, focused on the technology service industry, digital content, and biotechnology;
- Neihu Technology Park, focused on ICTs and biotechnology;
- Taichung Software Park, focused on digital content and Internet of Things (IoT) applications;
- Kaohsiung Linhai, Data, and Software Industrial Parks, focused on sectors including petrochemicals, iron, and steel; metal processing and precision machinery; and ICs, optoelectronics, communications, and environmental technology.

Another important organization is the Taiwan Institute for Information Industry (III) which Taiwan formed in 1979 to "promote effective application of information technology, increase national comprehensive competitiveness, create preconditions and environment for information industry to develop, and to strengthen the competitiveness of information industry." The III has contributed to pioneering R&D in ICTs, the deepening and broadening of information applications, the training and education of talent in the field, and the participation in building infrastructure for national information technology.[28]

Taiwan has long been trying to strengthen its competitiveness in the life-sciences industry (though these efforts have achieved mixed success). In 1984, it established the Development Center for Biotechnology (DCB) as a non-profit R&D organization with the support of DoIT and MOEA. Its missions are to establish internationally competitive R&D capabilities and to promote and upgrade the domestic biotechnology industry by coordinating government agencies, research institutions, universities, and the private sector. To this end, DCB strives to act as the industry's partner, coordinating resources among government, academia, and private companies. DCB remains a key force in building and upgrading Taiwan's biomedical infrastructure, developing key technologies, and growing Taiwan's professional workforce. With over 400 dedicated researchers and state-of-the-art facilities, DCB today specializes in developing biologics and small molecule drugs, botanical drugs, and the technologies required for preclinical testing.[29]

It's also important to note that while Taiwan generally fields a "top-down" innovation system, it also benefits from "bottom-up" coordination between key industries and the Taiwanese government, particularly coordinated through key Taiwanese industry associations. For instance, TEEMA, the Taiwan Electrical and Electronic Manufacturers' Association, features over 3,000 member companies which collectively account for 45 percent of Taiwan's gross domestic product (GDP). TEEMA is one of the eight largest national industrial trade groups in Taiwan—others including associations focused on automotive, agriculture, biotechnology, textiles, etc. These industrial trade groups annually collect and report to the Taiwanese government key information on sectoral performance, such as value-added, exports, employment, productivity, etc. The information is then used by the Taiwanese government and private sector to develop innovation and competitiveness strategies for the relevant economic sectors.

It should also be noted that Taiwan's modern economy has been built on a wide, interconnected network of small and medium-sized enterprises (SMEs). These SMEs had the flexibility to specialize in niche markets for short-cycle technologies complementary to innovations coming out of Silicon Valley, such as integrated circuits and equipment for personal computers (PCs).

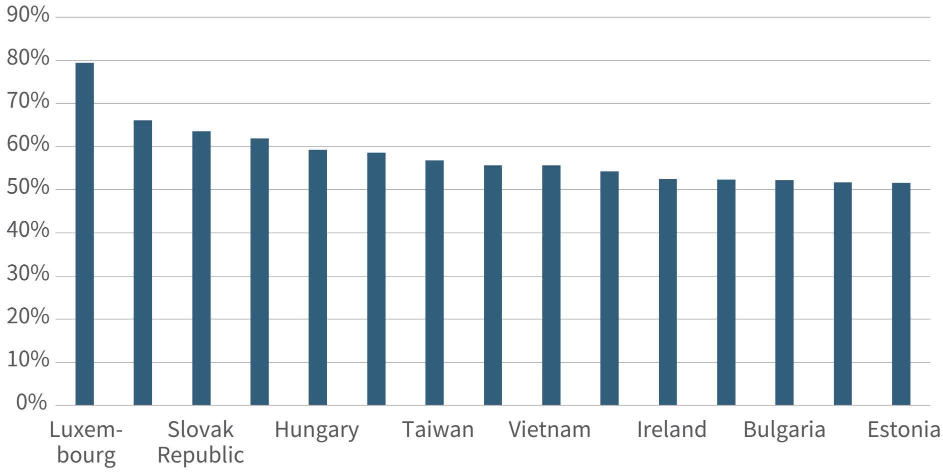
Historically, some of the most significant innovations to have been produced in Taiwan include the floating gate transistor (in 1967, by Simon Min Sze and Dawon Kahng, the USB flash drive (by Pua Khein-Sang), the wireless broadband communications standard WiMAX, and the integrated laptop projector.

5. Taiwan's Innovation Strategy

Over the last seven decades, Taiwan's innovation—or, put differently, its economic and industrial development strategy—has evolved from a "factor-driven," to an "efficiency-driven," to a "technology- and innovation-driven" approach. In the 1950s, Taiwan's factor-driven approach focused on import substitution industrialization and the development of light industries such as textiles and toys. In the 1960s and 1970s, Taiwan shifted toward an export-oriented, efficiency-focused industrialization strategy focused more on products such as auto parts, bicycles, metal products, and industrial components. In the 1980s, Taiwan shifted more toward high-tech, export-oriented industries, especially electronic components and ICT products. Then really starting in the 1990s and beyond Taiwan pivoted to an innovation-driven approach that focuses on increasing value-added and exports from high-tech industries, diversifying its industrial structure, and expanding its production and export of knowledge-intensive services. In these decades, Taiwan grew ever more competitive in ICT and electronics industries, notably semiconductors, and grew its competitiveness in other high-tech sectors such as biotechnology and solar/clean energy. One interesting point here is that because Taiwan enjoys few free trade agreements with other nations, and so its exporters have often confronted high tariff rates in many nations, Taiwan has tried to emphasize competitiveness in industries, such as ICTs and semiconductors, where it can enjoy the benefits of tariff-eliminating agreements such as the Information Technology Agreement (ITA).

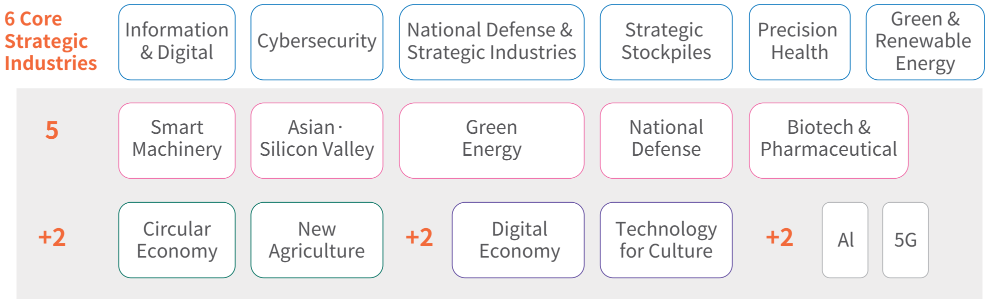
Over the years Taiwan has become deeply embedded in global value chains (GVCs) for the production of high-tech goods.[30] In fact, Taiwan ranks among the world's most GVC-dependent countries, ranking seventh in terms of Organization for Economic Cooperation and Development (OECD) countries' GVC participation rates as a share of total exports (which is slightly down from being the second-most GVC-dependent country for exports in 2013).[31] (See Figure 7.11) Taiwan's economy has become heavily export-dependent, with exports accounting for almost 70 percent of the country's GDP.[32] Taiwanese-headquartered companies are increasingly responsible for producing the value-added embodied in Taiwanese exports. By 2015, Taiwanese domestic value added accounted for about 70 percent of the value of Taiwan's gross exports from both the electronics and information industry sectors and about 62 percent of all manufactured exports.[33]

Figure 7.11. Countries' global value chain participation rate, as a share of total exports (2018)[34]



Today, Taiwan's innovation strategy seeks to leverage the country's existing strengths in innovation and R&D to develop cutting-edge new product applications and services with global potential. The country has articulated a so-called "5+2+2+2" strategy to advance the innovation and competitive capacity of six core industries: Information & Digital, Cybersecurity, National Defense & Strategic Industries, Strategic Stockpiles, Precision Health, and Green & Renewable Energy. Underpinning these core industries are five "horizontal technologies or platforms"—Smart Machinery, Asian Silicon Valley, Green Energy, National Defense, and Biotech & Pharmaceutical—which are supported by enablers such as the Circular Economy, New Agriculture, Digital Economy, and Technology, notably artificial intelligence (AI) and 5G. (See Figure 7.12)

Figure 7.12. **Taiwan's formulation of strategic industries and "5+2+2+2 Innovation Strategy"**[35]



Collectively, Taiwan's "5+2+2+2 Innovation Strategy" seeks to promote cross-industry technology integration with an emphasis on digitalization, Internet enablement, smart technology, and environmentally friendly technology. It should be noted that Taiwan's innovation strategy has been designed mindful of the need to help the country overcome the so-called "five shortages"—that is, the lack of sufficient land, water, power, manpower, and talent—needed to meet Taiwan's continuing economic growth objectives.[36]

Recognizing that AI will be a fundamental enabler of this transformation, Taiwan's MOEA has developed an "AI-on-Chip Strategy" that seeks to advance "pervasive AI" across Taiwan's smart manufacturing, semiconductor, robotics, and autonomous driving ecosystems. This is important, for as the Carnegie Endowment for International Peace's Evan Feigenbaum has compellingly written, "Taiwan faces headwinds because of the concentration of so much of its comparative advantage into hardware manufacturing, just as next-generation industries are moving toward an emphasis on the integration of software and hardware."[37] As he elaborates, Taiwan hasn't effectively transitioned from a hardware-dominant ecosystem to greater emphasis not just on software but especially on hardware-software integration.[38] As he explains:

> Taiwan should prioritize carving out a specialized niche in the newly emerging, rapidly evolving global value chains for knowledge industries like AI and IoT… There is considerable opportunity to integrate software, AI, and data science into established industries ranging from healthcare to education to information security.[39]

As Feigenbaum notes, to achieve this, Taiwan will need to catch up in global user-centric ecosystems and business models and build its science, technology, engineering, and mathematics (STEM) talent base in these fields.[40] This is also an area of greater potential U.S.-Taiwan collaboration. As Feigenbaum notes, one of the challenges Taiwan will confront in the AI field is that a lack of scale in its economy disadvantages its ability to collect the large data sets so important to training AI systems, disadvantaging it, particularly in comparison to China, which not only has access to large data sets but is restricted by little compunction regarding citizens' private rights. The point is that mastering AI in the way Taiwan has mastered semiconductors will be vitally important for the country's future economic competitiveness.

Overall, Taiwan's NIS benefits from enjoying a "whole-of-government" strategy that generally exhibits regulatory and policy coherence, as well as coordination between sectors and coordination between the government and industry. While there are a plethora of science and technology (S&T) policymaking/policy-enacting bodies across the Taiwanese government, they are generally very good about coordinating and communicating with one another so that their policies can have the maximum intended effect and so that confusion and conflicts are minimized. As noted, private sectors also tend to coordinate with one another on innovation policy to pursue a singular national (as opposed to commercial) goal.

The Taiwanese government has endeavored to use regulatory sandboxes to encourage experimentation, R&D, and commercialization of emerging technologies. For instance, MOEA's "Sandbox for Unmanned Vehicle Project" has created a sandbox offering "a sound and safe environment for innovative experimentation" in the development of autonomous buses, drones, and autonomous ships. Firms spinning off from research conducted in Taiwan's science parks often receive help in streamlining regulatory processes (e.g., such as exemplified by an interesting example of ITRI and a UVC water sanitation device being used for the earthquake response in Turkey).

Taiwan has endeavored to bolster the quality of its intellectual property rights environment in recent years. Taiwan has amended its Trade Secrets Act several times to strengthen control over and increase penalties for the theft of trade secrets. In May 2022, it established economic espionage as a criminal activity. In January 2023, further reforms were made to strengthen trade secret protection and to establish a more professional, effective, and internationally competitive IP litigation system.[41]

6. Business Creation and Financing in Taiwan

Other East Asian economies such as Japan and South Korea have traditionally relied on a group of major conglomerates and vertical integration of the production process for their innovation and technological development. In contrast, Taiwan's modern economy was instead built on a wide, interconnected network of small and medium-sized enterprises (SMEs). Although, to be sure, in the years since some world-leading companies, such as TSMC, have emerged.

This strong start-up culture is partially the result of Taiwan's investments in science and technology parks, most notably the Hsinchu Science Park. These parks provide engineers with a place in which they can conduct their research, collaborate with like-minded innovators, and expand their networks. Ultimately, Taiwan's science parks have served as incubators for nascent start-ups, surrounding entrepreneurs with the resources necessary to commercialize their inventions. Such technology and R&D hubs resulted in now-major international technology companies like Taiwanese Semiconductor Manufacturing Company (TSMC) and United Microelectronics Company (UMC). TSMC and UMC are two of the largest semiconductor foundry companies in the world and play vital roles in the global supply chain, and both still have their headquarters and main operations in Hsinchu Science Park. More recently, Taiwan's technical universities have served as incubators for start-ups as the country shifts toward innovations in emerging technologies that depend more on basic scientific research.

Taiwan's start-up ecosystem was also fueled by one of the first developed venture capital (VC) ecosystems outside of the United States. Taiwan's close ties with the Silicon Valley innovation network made the business sector much more conducive to VC, and Taiwan's returning successful entrepreneurs were eager to reinvest their capital in the next generation of start-ups. As Professor AnnaLee Saxenian describes it: "At this point, the local system of entrepreneurship gains the potential to become self-sustaining: local knowledge begins to accumulate, lessons and experience are shared across firms and generations, and repeat entrepreneurship becomes both common and acceptable."[42] The majority of successful start-ups also went public and listed themselves on the Taiwan Stock Exchange (TASE). As of December 2022, the combined market capitalization of TASE was 195 percent of Taiwan's GDP, compared with 193 percent for the United States.[43] However, there is concern that Taiwan has less zero-stage venture funding, especially compared to the world leader, the United States.

Taiwan's start-ups and VC ecosystem have also been supported by a collection of government incentives and subsidies. For example, to promote the development of Taiwan's VC industry, 20 percent of capital invested in technology-intensive business ventures by individuals or businesses was tax-deductible in the 1980s. Currently, the Taiwanese government provides awards, grants, and loans for small businesses to expand and conduct research. Taiwan's R&D tax credit rate was recently raised to 25 percent of qualified research expenditures and 5 percent of expenditures on equipment for advanced manufacturing. Taiwan also provides relatively generous tax support for investing in capital equipment.

Taiwan's taxation system has historically been viewed as vexing for startups in the country. As one observer noted (in 2013), "The government taxes them [startups] on the paper value of their company. That means investments from venture capitalists are taxed even if companies have yet to make a profit."[44] By 2019, Taiwan's Act for Development of SMEs and Startups attempted to address some of these challenges, with the bill's "taxation environment" chapter addressing tax incentives for knowledge innovation and digital transformation, including tax credits for investments in the segments of smart machinery, IoT, AI, and system integration. Further, to better support startups' exit strategies (e.g., M&A) the Taiwanese government revised the Business Mergers and Acquisitions Act to allow individual shareholders of a startup to defer tax payment for the shares they purchase at premium prices from the surviving company after the startup is acquired, to spur M&A of startups.[45]

7. Taiwan's Innovation Culture Today

A cultural willingness to experiment and take risks represents an important element of a country's national innovation system. Participants in ITIF's roundtable on Taiwan's NIS held the view that perhaps there was more of a cultural willingness to experiment and take risks in the post-World War II years, as Taiwanese citizens and executives were especially focused on "nation building" and crafting a globally competitive economy. There was a sense that younger generations perhaps lacked the entrepreneurial zeal of their forbearers. One interviewee gave the example of younger entrepreneurs seeking to launch coffee shops instead of high-tech companies.

That said, Taiwan remains quite entrepreneurial overall. According to the Global Entrepreneurship Monitor (GEM), 15.5 percent of Taiwanese aged 18–64 intended to start a business in the next three years, as of 2020.[46] The comparable figures for Germany, Japan, and the United States were 10.7 percent, 4.3 percent, and 12.5 percent, respectively. And 11.1 percent of Taiwanese aged 18–64 owned and managed an employee establishment for more than 42 months, compared to 6.2 percent, 7 percent, and 9.9 percent for citizens of Germany, Japan, and the United States, respectively. As the GEM notes, Taiwan's total early-stage entrepreneurial activity (TEA) rate "is higher than many other high-income GEM economies, indicating a healthy entrepreneurial dynamism that is difficult to achieve in highly industrialized economies."[47]

While Taiwan still maintains a fairly entrepreneurial culture, a smaller share of entrepreneurs possess S&E backgrounds. According to a 2018 study by PwC, only one-third of entrepreneurs in Taiwan have a STEM background, whereas almost 60 percent of entrepreneurs have a background in the liberal arts.[48] Thus, Taiwan is not only producing fewer graduates with the skills required to compete in advanced industries, but these graduates are also less likely than their counterparts to start a business. One area of focus in Taiwan's 2021–2024 S&T Development Plan is the blending of disciplines in higher education. For example, extending more business and management courses to S&E students and more technical and engineering courses to business and liberal arts students. Taiwanese policymakers hope that this blending of subjects will make graduates more capable entrepreneurs and more able to combine ideas from different fields to create innovations.

That said, overall, participants expressed the view that Taiwan's private sector is less risk averse than the private sectors in countries such as Korea or Japan, although Taiwan's firms (outside of a handful of sectors like semiconductors) were not nearly as entrepreneurial or risk-taking as their U.S. counterparts. Several interviewees judged Taiwan's government/bureaucracy to be somewhat risk averse; however, others noted that this may be changing, citing recent experiences such as with regulatory sandboxes. While still risk averse, the Taiwanese regulatory bureaucracy takes a more practical approach to risk management than their peers in Korea or Japan. Whereas Taiwan seeks to conduct projects and activities in a way that removes the largest amount of risk, regulators in Korea and Japan tend to be more eager to avoid projects altogether if they cannot remove all associated risks.

Unlike the United States, Taiwan is not beholden to a free-market ideology but instead adopts policies that policymakers feel will best hasten its technological development, even if that means government involvement (especially in key industries). Nation-building has been a consistent goal of the Taiwanese government since its founding. Taiwan also differs from countries like China and Japan in that it is much less beholden to traditional East Asian principles like deference to authority. Taiwan tends to be much more free-thinking and individualistic.

8. Improving Taiwan's NIS

Almost all of the participants' recommendations for how Taiwan's NIS can be improved concern multinational corporations' activities and foreign direct investment in Taiwan. Among the steps participants wish could be done to improve Taiwan's NIS are:

- Increase transparency in dealing with Taiwan's bureaucracy for multinational corporations.
- Promote foreign direct investment in digital technologies rather than in manufacturing capabilities.
- Be more attractive to software MNCs to boost Taiwan's software development ecosystem.
- Get VCs to invest in early-stage start-ups and become more risk-taking.

- Work with the U.S. government and industry to coordinate on policy that will boost the countries' mutual innovation capabilities.
- Promote Taiwan's engagement in international forums such as the International Civil Aviation Organization, Interpol, and the World Health Organization.
- Increase funding for higher education. As one 2015 report noted, "The number of universities/colleges has grown from fewer than 50, 10 years ago, to more than 160 now. [Yet] The budget for education has remained around 4% of GDP over the period despite the quick increase in the number of universities."[49]
- Increase the number of qualified, high-level R&D personnel. As the aforementioned 2015 report writes, "The majority of people with PhD degrees are working in universities—close to 70%—or in government research instates-around 20%. Therefore, only the remaining 10% are serving the private sector." Taiwan should improve the quality and standard of industrial R&D while focusing on strengthening the relationship and interaction between industry and academia.[50]

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Chapter 8

Lessons from Comparative Analysis of Five National Innovation Systems

JEONG Hyeok

This study compared the national innovation systems of five economies: The United States, Korea, China, Japan, and Taiwan. With this comparative analysis, we sought to understand their historical and institutional features and nature. We found genuine differences among these five economies in terms of performance measures of science and technology inputs and outputs, finance, outcomes, government role, culture, and innovation implementation systems.

There were some noticeable differences between the U.S. and the four Asian economies, particularly in the role of government, risk-taking attitudes, and financing schemes for innovation. Four Asian economies are engaged in, by and large, more active roles of government in promoting and shaping the directions of innovations but are more conservative in risk-taking and related finance, such as venture capital and foreign investment for start-ups than the United States. Four Asian economies are strong in advanced manufacturing but weak in ICT services and bio industries compared to the U.S. Four Asian economies have a solid pool of general human capital, but their frontier human capital and research for ground-breaking idea creation are fairly behind the U.S. So, some elements of commonality regarding innovation promotion seem to exist.

At the same time, however, there also exist equally broad spectra of differences among the four Asian economies of our study from these three distinctive features of innovation, let alone the various dimensions of performance measures. Although Japan's global stance on innovation is still strong, it is in a declining trend and, in fact, behind China, Korea, and Taiwan in many performance measures of innovation and comparative advantages of production in most of the advanced industrial sectors. The roles of government regulation and politicization of business are very different between China and the rest of the three Asian economies. Despite the similar strength in the semiconductor industry between Korea and Taiwan, Taiwanese industrial composition is much more concentrated in selected industries only, and SMEs are the main drivers of innovation in Taiwan. In contrast, large-scale companies are the main drivers of innovation in Korea. Furthermore, there are more diverse sets of advanced industrial sectors, the LQs of which significantly exceed unity compared to any other countries in the world. That is, Korea has a more balanced set of advanced manufacturing industries with comparative production advantages than any other country in our study. In sum, variety seems to be a rule for the shape of existing NIS even among the successful nations of innovation, not surprisingly because the history, geo-political situation, and the social and economic development background of innovation all differ among these five economies.

However, we may draw two kinds of lessons from this comparative study. First, we can sort out the strengths and weaknesses of each nation's innovation system and look into the areas of improvement for each nation, learning from each other's NIS as we did in this study. Second, we can explore the room for mutually beneficial collaboration or partnership of innovation among the selected combination of economies in order to expand the scale and also to consolidate the scope of innovation for each nation. Seeking these kinds of lessons is hardly easy or straightforward; it involves so many complications. Here, we only suggest some visible lessons that our study has clear implications.

1. Lessons for the Areas of Improvement for Each Nation

There is no single best model of NIS for every nation because not only the historical, geo-political, and economic backgrounds but also the national strategies differ across nations. However, the observed differences in performance measures of innovation across countries are substantial, and mappings between institutional and knowledge inputs and the outcomes of innovation seem to exist. Thus, from our comparative study, we may infer the areas of improvement to promote the capacity and performance of innovation for each nation, which is documented as follows for each of the five economies.

1.1. China

China has shown impressive growth in many indices of higher education and research in relation to quantitative expansion. Furthermore, Chinese technology catch-up in many advanced manufacturing sectors was truly remarkable. Despite such visible performance in innovation and advanced industrial production, China suffers some fundamental problems in the domain of innovation.

First, the foundation of human capital production in relation to innovation is not solid. The "frontier human capital," a key to sustainable innovation for advanced science and technology, is not self-sufficient yet. The speed of the quality improvement of Chinese research universities and the growth of their publication records are indeed impressive. However, the Chinese mass of world-class research universities is still slim compared to its size in various dimensions. Furthermore, the top-notch researchers and faculty of those universities are either educated outside of China or imported from abroad. Furthermore, the higher education system for the general public is still very weak. Hence, many Chinese students need to go abroad for graduate studies.

Second, the Chinese science funding system, as well as the support for promoting incentives for innovation, needs improvement. While the Chinese IP system has improved to give more certainty to inventors, it still involves substantial politicization. Chinese state-owned enterprises often crowd out more innovative private enterprises. This is because the Chinese government *directly* engages in the entry/exit decision of business activities. Recently, the overall direction of market liberalization has been reversed, and the politicization of business has increased. These changes would tend to demote the incentives for innovations in the private sector.

Third, current Chinese strategies for acquiring foreign knowledge and technology demote foreign innovators' incentives to invest in China. Such strategies include enforced technology transfer to gain access to Chinese markets, legal pressures to compel foreign companies into licensing their technology at reduced rates, unauthorized appropriation of foreign intellectual property, and state-backed acquisitions of foreign enterprises. Once the knowledge and technology are acquired, China supports its domestic champions with subsidies and market protection to enhance their development and international competitiveness. This strategy would work for Chinese benefits in the short term but may not in the long term. Fixing this short-sighted strategy seems necessary for China's sustainable stream of innovations.

Fourth and perhaps the most critical challenge to the Chinese innovation system is the recent tendency toward reinforcing its "isolation" from the international community and also the attempts to form a regional block of economic order. Many advanced and developing countries started to realize the extent of the unfair trade practices in combination with the unfair tactics of technology acquisition and to take proactive measures to defend their losses against China by distancing from China under the name of "diversification." Such an atmosphere among international communities in forming international relations, political or economic, with China involves serious risks of either regionalizing China or creating antagonism against China. This will be a critical barrier for China to benefit from global idea sharing, another key to sustainable innovation. Another driving force of reinforcement of Chinese isolation from global idea-sharing is its attempts to establish and spread indigenous technology standards for ICT products. Despite existing international standards, China aims to develop unique national standards for various high-tech and ICT products. This may be a strategic groundwork for future tech dominance in the global market or simply a protective measure against the tech dominance of other countries. Either way, this creates a huge barrier to global idea-sharing. The Made in China (MIC) 2025 initiative aims to promote market-driven outcomes and commercial applications of innovation in order to strengthen domestic production reducing Chinese reliance on foreign influences. It is unclear if this is a sound strategy in the domain of innovation.

The fundamental source of Chinese power is its size. This is not simply because the size allows the economies of scale in production or the control of market access but also because size allows repeated failures of innovative activities in fishing out successful innovations or business opportunities, hence expanding the scope of trial and error for success. This is a huge benefit in finding innovation opportunities. At the same time, however, this involves huge costs. There are explicit and direct costs of inefficient resource allocation for such practices. The true costs of this innovation model are latent. Once the NIS and the potential innovators get used to this ample room for trial and error backed by government subsidy and the sacrifice of excessive failures, the inefficiency for innovation becomes a rule, making the overall attempts of innovation sterile. This tendency can be reinforced under the political governance of China. Furthermore, there exists a limit to the allowance of too many failures to pick out a few good ideas, even for China, if the pool of idea generation is closed within the domestic boundary. Thus, the government-led and size-dependent NIS of China would soon present serious challenges to Chinese innovation in the near future. Transforming the status quo regime of NIS, as well as the political governance backing the current NIS into a new one based on efficiency and openness, is the fundamental area for China to improve. This is not a simple policy issue. This is a social system issue. Furthermore, this model has been the basis of short and medium-term success in the past. Hence, it may well be hard to turn around. However, governance reform and strengthening legal compliance with IP protection for domestic and foreign technologies are indispensable prerequisites for Chinese NIS to make progress toward sustainable innovation.

1.2. Japan

Japan was a model country of innovation in the 1960s and 1970s, peaking in the early 1980s. The sign of a slowdown of innovation and productivity growth was shown around the Plaza Accord, and then the long-lasting stagnation, the so-called "lost decades," started in the 1990s until recently. Although Japan's stance on global innovation is still firm in many fields, a visible sign of a sustainable turn-around from the last three decades of stagnation is yet to come, which may be due to the following challenges in revitalizing innovations in Japan.

First, Japanese NIS shows some similarities in essence, compared to Chinese NIS in the following sense, despite the apparent differences between them in political and economic systems as well as in culture. The most striking similarity between Japanese and Chinese NIS is their "closedness" in innovation in essence, although the reasons behind the closed nature of each country's NIS differ between the two. For example, both countries tend to pursue their own standards when manufacturing ICT products. China's pursuit of its own standards seems to be motivated by the intention of creating its own regional league of innovations that are less prone to external influences. Japan's choice of idiosyncratic standards, however, is related to cultural factors of risk-averseness to changes, hence its history and location dependency in the evolution of innovations. This factor results in preferences toward gradual and localized improvement rather than the ground-breaking disruption all at once. Thus, Japanese closedness in innovation is an outcome of Japan's own social values rather than coming from intentional policy strategies like in China. However, the consequence is the same. It creates a tendency to close the idea-sharing circles, leading to the Galapagos Island syndrome. We already noticed such experience in the Japanese telecommunication industry. This may prevent Japanese innovations from being scaled up globally, no matter how valuable those innovations are.

There are other dimensions of closedness that would affect Japanese innovation, such as low mobility of researchers across companies and universities, a corporate culture of closed and self-sufficient in-house R&D system, lack of innovation ecosystem of knowledge spillover between the successful incumbents and new start-ups, and the weak international interactions in both academic as well as business communities. These phenomena all share a common element: closedness for stability. These tendencies limit the pool of idea sharing locally and globally.

Second, some socio-economic factors such as the notion of lifetime employment, seniority wage system (*Nenko Joretsu*), dual labor market (fostering disincentivized and unproductive *haken* workers), and various regulatory measures for administration procedures and entry/exit dynamics create the tendency of "rigidity" in the domain of innovation. They seem to come from the strong social preferences for "stability" and "perfectionism" in Japan. In fact, those socio-economic conditions were the main basis of the accumulation of high-standard basic technology and engineering skills in Japan. Such persistent and continuous accumulation of incremental improvements is usually an important driving force of innovation when there are few paradigm shifts in science and technology. The same tendency, however, can be a critical barrier to ground-breaking innovations, the so-called creative destruction, which matters more than the incremental inventions when the paradigm shifts in science and technology are as rapid as is happening these days all over the world. Japan needs to make fundamental institutional reforms to rebalance these two forces of innovation and regain its momentum.

Third, our comparative study revealed some problems with Japanese innovation financing schemes for start-ups in terms of both size and composition. The size of Japanese VC investment for start-ups, relative to total GDP, falls short too much compared to the other three Asian economies, let alone the U.S., as we explored in Chapter 6. To recap, the total investment for Japanese start-ups in 2022 was $6.7 billion, while it was $238 billion in the U.S. and $69.5 billion in China. Korean VC investment for the same period was $5 billion, which is heavily criticized as too low by the Korean innovation community, while the Korean total GDP is about 40% of Japan.

Japan and Korea share a similar strategy of promoting industrial sectors through active public-private partnerships. However, in terms of R&D investment composition, Japan and Korea show a sharp contrast. The private companies' share of Japan's R&D investment in 2020 is only 4% (the remaining portions are 53% in the public sector, 40% in universities, and 3% in non-profit organizations). The same share is 77% in Korea. That is, the public-private partnership for innovation is led by the public sector in Japan, while it is led by the private sector in Korea.

Fourth, universities play a critical and complementary role in commercial innovations. Hence, industry-university collaboration is crucial for sustaining innovations. Our comparative study reveals the weakness of Japanese industry-university collaboration compared to the other four economies. Most of all, industry funding for university researchers is fairly low in Japan. The average level of industry funding per university researcher is only about $5,000, while it is about $30,000 in South Korea and Germany. The average U.S. level of industry-university R&D investment is 1.75 times of Japan for the 1981-2019 period. Furthermore, only 3.9 percent of the university-developed technologies are licensed to start-ups each year in Japan, while it is 17.1 percent in the United States. This is partly because Japanese universities focus on basic research, not much on applied research or development. However, the corporate culture of the closed in-house research system of Japanese companies is another contributing factor to this low industry-university collaboration. Both sides do not have strong enough demands for each other in terms of idea creation in Japan.

Fifth, risk aversion in establishing business enterprises seems particularly strong in Japan. Fifty-five percent of potential Japanese entrepreneurs in the 2015 World Values Survey suggested that they were afraid of failure, which is the second-highest rate in the world. This risk attitude toward entrepreneurship results in the lowest entry rate of new enterprises of Japan among OECD members. Only 1.9% of the 18-64 workforce group attempt to establish new businesses in Japan, while 4.9% of the same working-age group are engaged in establishing new enterprises in the U.S.

Sixth, a more fundamental and long-term challenge for Japanese NIS is the imbalanced demographic structure induced by low fertility combined with aging. Maintaining the stream of innovations would be difficult because the potential population mass of idea generation shrinks with the declining population. Furthermore, the aging workforce may lower the already low Japanese productivity growth. However, this demographic imbalance is a common problem in all four Asian economies in our study, not just for Japan, and this population problem is likely to be reinforced in the near future.

In the case of Japan, the areas to improve sustainable innovation in Japan are subtle because they are rooted in social, economic, and cultural conditions rather than in straightforward policies. However, some issues, such as the lack of financing for innovation from both public and private sectors, labor market conditions of the seniority wage system and *haken* workers, and corporate culture of closed in-house R&D system, can be put on the table for policy reforms.

1.3. Korea

There is a myth that there exists a common Asian model of social and economic development, e.g., based on government-led industrialization, quantity expansion of inputs rather than on productivity growth, stable but rigid labor market, and so on. In part, it is true. There indeed exist some common elements among the successful industrializing Asian economies in terms of success and challenges of the prospects of general growth and development as well as the innovation system. Thus, some challenges for Chinese and Japanese NISs seemingly apply to Korean NIS, such as rigid labor market conditions of the seniority wage system and dual labor market, risk attitude toward entrepreneurship, weakness of finance, particularly venture capital investment for start-ups and the demographic imbalance with a declining population. However, our comparative study clarified that the spectrum of differences in those seemingly common elements among China, Japan, and Korea is as wide as that of the differences between the four sample economies of Asia and America. In fact, for some dimensions of NIS, e.g., the size and the importance of the private sector in R&D investment and the openness of trade and idea sharing the Korean position belongs to the end-side of the spectrum near the U.S. In another dimension, such as the inter-governmental coordination for science and technology policy, the Korean position is closer to China in the sense that coordination mechanisms are well organized and explicit. Furthermore, the Korean model of economic growth was indeed production inputs-based growth as is typically imaged like in Japan, but the main engine of Korean growth was transformed to productivity-based growth, the evidence of which is provided in Chapter 4 from the long-term growth analysis in Jeong (2018, 2020). This transformation is rarely known, even among Korean policymakers and scholars. Thus, Korea has its own strengths and weaknesses in the domain of innovation compared to other industrial powers in Asia. Our comparative study suggests that the following areas need particular attention to improve for Korean NIS.

The first and most critical problem of Korean NIS is the various kinds of unfavorable institutional and policy environments for risk-taking. This is different from Japan's risk aversion, which is based on social preferences for stability. Korean society is fairly dynamic and adaptive to changes and external shocks. However, there are institutional arrangements and market environments that demote active risk-taking for entrepreneurial activities. For example, policy loans for targeted industries played an important role during the take-off period of industrialization. Due to institutional inertia, policy loans still play an important role in supporting failed industries or SMEs. Oddly, the policy loans supporting SMEs are based simply on size and the track records of past loans, whether the businesses are successful or not because such screening practice is convenient for banks. Thus, tentatively innovative but new firms lose access to credit. This is deadly for the innovation segment of new entrants. For a similar reason, venture capital investment for start-ups is not as large or active as in the U.S. This creates a vicious circle between the lack of urge to develop risk management instruments in the financial sector and the lack of risk-taking among potential entrepreneurs.

Furthermore, the incumbent entrepreneurs also suffer from too high cost of risk-taking. Two critical factors for this are: (i) bankruptcy costs are too high, and (ii) labor adjustment is too costly because of the rigidity of wage setting and hiring/firing. Given these costs for business activities, the scope of taking risks for creative destruction is supposed to be shrunk. Thus, Korea's human capital, despite its world-class quality for the general public, is not fully utilized for Korea to become one of the solid innovation-leading countries.

The second and related problem is Korea's lack of experience and low productivity in the software service sector. Korea's capacity for hardware manufacturing power is strong, and it has accumulated a variety set of technologies and tacit knowledge in constructing and manufacturing tangible things. This is because the financial sector is not sophisticated enough to fund the intangible high-risk-high-return service businesses. This is not simply about the lack of service sector in Korea. In fact, the Korean service sector is large but filled mostly with low-risk-low-return service businesses. That is, this is again related to the weak financial sector and lack of development of risk management, hence demoting risk-taking. This is a bad fit for the current era of AI. However, it is important to acknowledge that to overcome this challenge, Korean NIS should not overturn its existing strength in manufacturing. In fact, innovation in manufacturing needs to be strengthened in Korea, but it needs to move forward in the direction of integrating software services into more sophisticated manufacturing frameworks.

Third, Korean R&D is too much oriented toward "development" over basic research so that Korea falls short of some critical source technologies and equipment. This is the opposite situation of Japan. Korea's corporate R&D as well as industry-university collaboration should place more emphasis on basic research, the area of which the Korean government can nudge.

Fourth, as in many Asian economies, Korea faces the multi-dimensional challenges of demographic imbalance together with a declining population. Problems related to the possibility of lowering productivity from aging and the reduced mass of researchers have already been discussed before. However, the speed of lowering fertility is more dramatic in Korea, so Korea should make many urgent reforms to adapt to these fundamental changes, particularly in the areas of education, the pension system, and regional development. Another important paradigm shift Korea should make is the reinforcement of openness in terms of not only trade and investment but also labor immigration and idea sharing.

Fifth, the Korean government has acknowledged the grave significance of science, technology, and innovation for Korean development and established an active governance system such as the Science, Technology, and Innovation Office (STIO) in order to coordinate inter-ministerial innovation policies equipped with executive as well as planning functions. This is a rare case. However, despite such well-developed governance, its effectiveness is unclear. This is because the Korean government lacks long-term and coherent national strategies for science and technology development, which should be consistent with political regimes. The Korean government's long-term strategy for promoting national innovations should acknowledge Korea's genuine vulnerability to external shocks. Korean NIS does not have as much room for isolated innovation as China. Korean government needs to recognize the urgent need for a global partnership for idea sharing. An innovation alliance is at least equally important to Korea's economic and military alliances.

1.4. Taiwan

The strength of Taiwan's NIS is the strategic ecosystem of innovation via government-industry collaboration. Successful innovating companies like TSMC and UMC emerged in Taiwan due to the strategic policy efforts of ITRI, which is close to the U.S. model of DARPA. A unique feature of Taiwanese NIS is that those successful innovators grew big, starting from SMEs in the areas that the Taiwanese government identifies as strategically promising. To nurture the SMEs in those strategic areas, Taiwan uses the same strategy as China, i.e., offering opportunities to multinational foreign companies to trade between the access to domestic market and the access to foreign technology. Furthermore, Taiwan established an ecosystem such as the Science Park to promote innovations among SMEs to maintain the above dynamics. However, Taiwanese NIS has recently faced visible challenges.

First, there is an important caveat in the above strategy: The strong tie to the Chinese market. The successful Taiwanese companies by utilizing foreign technologies could grow because Taiwan has had an extra benefit that other countries do not have, i.e., access to mainland China as their backyard market so that the Taiwanese SME innovators were not exposed to global market competition until they grow big enough. This has been an important backbone of the Taiwanese economy in general and was a critical pedestal for Taiwanese companies like TSMC to transform into a global innovator. Whether this is a benefit for Taiwan these days is unclear because the access to the Chinese market for a company like TSMC becomes uncertain, so the "established" Taiwanese innovators would better diversify their sales market. However, at the same time, access to the Chinese market is still important for the current SME innovators because of the accumulated practices of interaction between Taiwan and China. Thus, there seems to exist a tension between the incumbent successors and the entrants with new ideas. Finding the right balance between the two groups in terms of the global market portfolio is an important challenge for Taiwanese NIS.

Second, the production and utilization of advanced human capital for innovation are weak in Taiwan compared to the rest of the four countries, as we discussed in Chapter 7. The main issues include a lack of investment in higher education, shortage of STEM skills among young entrepreneurs, shortage of Ph.D. in private sector R&D, weak industry-university collaboration, and weakening trend of internationalization. Many of these issues are similar to the Japanese situation. Human capital is a fundamental input for maintaining innovation flows, which can be independent from the reliance on access to foreign markets. Recognizing the recent uncertainty and vulnerability to access to foreign markets, Taiwanese NIS should reform the higher education sector by not only expanding the investment but also facilitating international human capital exchanges.

Third, there is a long-time standing 'scale' issue in Taiwan. In contrast to Korea, Taiwan's development strategy has placed much more emphasis on SMEs and domestic market orientation. As we discussed above, this strategy has worked quite well for Taiwan's development during the last half-century. However, in the era of AI, small scale is no longer a virtue because all AI-related technologies grow by feeding the large mass of training data, which requires a scale of domestic industries. TSMC takes part in the semiconductor industry's manufacturing segment and, hence, can maintain its prosperity through the expansion of AI-related industries elsewhere. However, with this kind of industrial development, there exists a fundamental limit to promoting "national" innovation via TSMC type of industrial advancement. This is particularly so when most of the surrounding enterprises are featured on a small scale.

A fourth and related issue is Taiwan's perhaps over-concentration only in selected sectors. In fact, the support only for a few selected sectors is the essence of the Taiwanese industrial strategy. This is an effective strategy for a country like Taiwan, where the SMEs and their domestic comparative advantages are emphasized. Furthermore, given the relatively small-scale economy, this selected support was necessary to scale up Taiwanese merit in the global market. Indeed, Taiwan's overall LQ of 2.1 for the ten Hamilton industry sectors is the highest in the world as of 2020, owing to this effort to support selected manufacturing. Taking a second look, however, this high overall LQ is because of the extremely high LQ of 8.93 in the semiconductor industry. The LQs of the other sectors are all lower than 2, most industries' LQs are lower than 1.5, and for IT and Information Services and Pharmaceuticals, LQs are lower than 0.5. The weak service sector, particularly for IT and Information Services, is a problem in China, Korea, and Japan as well. However, their LQs of IT and Information Services are 0.57, 0.84, and 1.05, respectively. Korea, a country with the second-highest overall LQ, also has a very high LQ in the semiconductor industry, and its LQ in IT and Information Services is lower than one. This way, Korea and Taiwan face similar challenges. However, the low LQ in IT and Information Services is an exception for Korea, and the LQs of most Hamilton manufacturing industries exceed 1.7, while the LQs of most manufacturing industries except semiconductors are lower than 1.5. These comparisons illustrate that Taiwan's concentration in semiconductors seems overshooting. This phenomenon is deeply related to the small-scale nature of the Taiwanese economy. Taiwanese NIS should find a way to overcome this problem.

1.5. United States

The United States is ahead of any country in the world from the perspective of the accumulated stock of innovations and also the level of frontier technologies at a significant distance. It is because the United States has strengths in a number of fundamental factors of innovations such as managerial talent, concentration of the world's top research universities attracting the best quality of minds from all over the world because of their competitive incentive system, openness to attract high-skill immigrants, good system of technology transfer from universities to the private sector, presence of public agencies like DARPA identifying and promoting ground-breaking innovations, strong risk-taking and entrepreneurial culture backed by legal and financial institutional infrastructure including active venture capital system for start-ups, good business climate, a large size of domestic market, continual emergence of frontier technology firms, especially in the IT sector, a strong intellectual property protection system, and balanced productivity growth across diversified sectors. Thus, regarding the status quo absolute stance as well as the institutional and cultural environments of innovation, the United States takes the lead position far ahead of other countries. However, the U.S. faces an important challenge: the momentum of innovation stagnated, and the trend turned to decline. When the innovation followers, e.g., the four Asian economies in particular the big countries like China, are catching up fast, the declining trend is a serious challenge and may not be an option for the U.S. to keep its leading position. The challenges may be in the policy areas. This section sifts only the essence of the challenges.

First, although Chapter 3 presented various issues behind the declining trend of U.S. innovation, for many of them, the source problem is the reinforced trend of manufacturing vacuum in advanced industries in the U.S. This phenomenon itself may not be a serious problem because the entire history of long-term development is about structural changes and the movement of resources toward service sector, particularly the high-tech service sector was a natural one.

However, as the globalization of the world has intensified, the international division of labor, as well as the specialization of production, has become more visible in the global value chain. This improved the overall efficiency of the global production as a whole. At the same time, this trend created a tendency for interdependent production structures across countries. During this process of globalization, the U.S. pursued “idea production,” e.g., software designs of high-tech sectors where value-added creation is the highest upstream position in the global value chain. In the meantime, the U.S. yielded the manufacturing sectors to other industrial powers of the world. This strategy created a *separation between idea production and final goods production*. Such separation happened not only for the U.S. upstream of the global value chain but also for other countries downstream of GVC. This strengthened the U.S. as the global leader in idea production but weakened the manufacturing capacity in key advanced industries of the U.S. and lost the comparative advantages of those industries, especially compared to the four Asian economies. The problem is that there is an asymmetry in nature between the manufacturing and service sectors. Adjustment of the investment in service sectors is flexible, but the investment in manufacturing is not. It is very difficult, though not impossible, to reverse the trend of the de-investment in manufacturing because vitalizing manufacturing requires built-in hardware and physical infrastructure and also the manufacturing-skill embodied workers, both of which are very difficult to reinstall. Therefore, the idea catch-up countries with solid ground of advanced manufacturing sectors, like the four Asian countries, particularly China, can move faster from the downstream to upstream than the idea frontier country with weak manufacturing ground can progress. It has become more visible, considering the development of AI technology. The U.S. is an obvious leader of AI in the world for now because the current stage of AI development is the initial one where ideas matter much more than the final products. Soon, the room for further development of AI will depend on physical applications of everyday life (because that is the nature and purpose of AI technology), which requires advanced manufacturing technologies in phones, cars, robots, and machines and equipment, i.e., the hardware.

Of course, such asymmetric development between the U.S. and the other idea catch-up countries will happen “if” the idea catch-up countries can effectively promote the sustainable stream of innovations. In sum, the essence of the challenges for the NIS of the four Asian economies is all about making this “if” come true by reforming the institutions and policies for innovation. The essence of most of the challenges the U.S. faces now is about overcoming the difficulty of this asymmetric situation. Correct recognition of this asymmetry and designing effective response strategies for innovation at the global scale, not just at the domestic level, is the most important challenge for the U.S. NIS to maintain its frontier position. The United States may well re-design the global alliance for the integrated innovation and production alliance on top of the trade and military alliances from the National Innovation System perspective.

Second, our comparison of the five NISs showed that the U.S. lacks the government-industry collaboration and strategic coordination mechanism between them compared to the four Asian economies. Various issues were discussed in Chapter 3, such as (i) the negative attitudes among the general public, media, and policy elites against new technologies and large tech companies, and the associated regulation measures (particularly in the context of data privacy), (ii) stagnant or declining government science and technology funding, (iii) short time horizon and the unwillingness of the general public and corporates to support investing in the future, (iv) little attention paid to the mission of boosting international commercial innovation competitiveness, and (v) the lack of long-term innovation strategies including the above-mentioned design of the global partnership of innovation are the surface consequences of this lack of government-industry collaboration or coordination mechanisms.

Third, the U.S. has the best research university system, but the scale of the production of STEM human capital out of such a system is smaller than needed. Specifically, except for the IT service sector, all advanced industrial sectors lack an engineering skill supply, and a large portion of STEM talents are effectively imported. Engineering skills are a critical ingredient of innovation, different from ideas because they are embodied in people. Fostering STEM talents is, in fact, an issue of the K-12 education system, which is a long-standing issue of American education. Thus, a more effective solution could be to create an international platform for STEM talent exchange to promote mutual learning among the participant countries.

2. Strategy for Innovation Alliance

A Key to sustainable innovation is "openness." The areas for the NIS to improve for each nation that we discuss in the previous section are mainly about how to promote openness to facilitate the sustainable stream of innovations. The boundary of openness can be different layers. It can be a domestic ecosystem among young start-ups, collaboration between large incumbent companies and small entrant start-ups for technology transfer and guidance, policy coordination between government and industry, human capital production coordination between university and industry, and the inter-country coordination for the global partnership for the products-idea division of labor. Legal and financial institutions, as well as market conditions and cultural environments, matter.

However, being open is very difficult in case of idea sharing or collaboration. This is another level of collaboration, much more challenging than being open for trade and financial investment. This is because the genuine properties of public good, such as "non-rivalry" and "non-excludability," apply to the idea. Creating a new idea involves an immense amount of fixed costs, but the marginal cost of using it is near zero (non-rivalry). At the same time, because of the intangible nature of an idea, it is very hard to exclude third parties or non-inventors from using it once it is spilled (non-excludability). Therefore, forming a partnership of idea sharing is almost impossible unless there exists a strong intellectual property ownership system combined with effective monitoring and enforcement or trust among the collaborators. At the same time, however, if the idea production is done in a closed and isolated manner, the 'fixed cost' of idea production increases by leaps and bounds, often beyond the threshold of realization. Thus, the installation of effective enforcement mechanisms for IP protection is a precondition for the collaboration of idea production. The shape of such enforcement mechanisms would depend on the "boundary of sharing." This section discusses some lessons about the potential strategic factors in designing the boundary of collaboration for idea production at a global level from our comparative analysis of NISs.

Innovation is not simply about idea production. An idea turns to innovation when it becomes *useful*. Thus, innovation is a combined outcome of idea production and actual production of goods and services so that both kinds of production activities cannot be separated to achieve true innovation. Due to the strong trend of globalization during the last half century, the tendency of international division of labor and the consequential dependence on domestic production structure across countries has been intensified, hence yielding the spatial separation between idea production and product production.

Therefore, there are two prerequisites in forming the international “innovation alliance”: (i) a strong mutual IP protection and enforcement system and (ii) the “idea-products production complementarity” among the collaborating countries. The analysis of the second condition involves serious academic research efforts, which this report will not pursue. Here, we present some critical facts that may guide such analysis.

In the previous chapters comparing the five NISs, we used two kinds of quantitative measures in diagnosing the current situations regarding innovations: (i) LQ from the Hamilton index for the comparative advantages of production of the ten advanced industrial sectors, and (ii) Global Innovation Index (GII) for the seven categories of innovation inputs and outputs. The LQ is about production structure, while GII is about the environments and results of innovation. Nine out of the ten industries in the Hamilton Index analysis are manufacturing sectors. The exceptions are the IT and information services. Thus, manufacturing strength, measured by LQ, does not necessarily imply strength in innovation. Interestingly, however, the correlation between the overall LQ and the overall GII scores is very high at 0.62 in log scales. This implies that innovation performance is closely tied to manufacturing strength empirically. This does not mean the direction of causality between the two. Identifying the causal direction will be crucially important in designing both innovation and industrial policies. What we can say from this simple correlation, however, is manufacturing strength cannot be isolated from promoting innovation.

Table 8.1 shows the 2018-2020 period average values of ten industries and overall LQs for the five economies. We may categorize the sectors into three groups according to the LQ score: weak for LQ less than 0.8 (yellow-colored), average for LQ in the 0.8-1.2 range (gray-colored), and strong for LQ higher than 1.2 (green-colored). This grouping is helpful in identifying the balance of strong areas. The overall LQ is highest in Taiwan, but this is because of the extremely high LQ in Computer and Electronics (8.93). There are six strong sectors, three weak sectors, and one average sector in Taiwan. This contrasts with China and Korea. Although China’s overall LQ (1.47) is lower than that of the Taiwanese, there are seven strong sectors and only one weak sector with two average sectors. Korea is the most balanced in terms of manufacturing strength: eight strong, on average, and only one weak sector. Japanese manufacturing strength seems to be anchored around average for most sectors. The United States has 6 weak sectors, two average and two strong ones.

This table provides us with an interesting crossover pattern of industry LQs among the five economies so that production comparative advantages differ across industry sectors. This indicates room for cross-sector collaboration in order to compensate for each country's weak areas of production. In fact, this comparative advantage idea is clearly the basis of international trade. We may apply a similar idea to structuring production between countries rather than to channel the sales of final products.

All four Asian economies are either weak (China and Taiwan) or average (Korea and Japan) in IT and Information Services, while Taiwan, Korea, and China are strong in Computer & Electronics. In contrast, the U.S. is strong in IT and Information Services but just average in Computer & Electronics. Given the complementarity between the two sectors, this identifies the presence of theoretical room for cross-sector production collaboration between the USA and the three economies of China, Korea, and Taiwan by mutually compensating their weakness with other's strengths. However, this collaboration requires a critical ingredient, i.e., the "mutual trust," being equipped with an effective monitoring and enforcement system among collaborators. Considering the current practice of Chinese IP protection and the public governance for tech dominance ambition, such cross-sector production and idea-sharing collaboration seems extremely difficult and ill-advised. However, visible opportunities for such collaboration do exist between the U.S. and Korea or between the U.S. and Taiwan, or among the three.

In fact, such crossover LQ patterns between the U.S. and Korea, Taiwan, or Japan are observed for the other sectors as well: six sectors (Electrical Equipment, Motor Vehicles, Fabricated Metals, Machinery & Equipment, Chemicals, Basic Metals) for Korea; four sectors (Electrical Equipment, Fabricated Metals, Chemicals, Basic Metals) for Taiwan; and four sectors (Electrical Equipment, Motor Vehicles, Machinery & Equipment, Basic Metals) for Japan. For the Other Transportation sector, Japanese weakness can be compensated by collaborating with the U.S., Korea, and Taiwan. This kind of crossover LQ pattern and the potential room for cross-sector collaboration need to be refined with a more detailed classification to make the collaboration work. For example, the

Other Transportation sector includes all transportation industries, such as aircraft and shipbuilding, other than motor vehicles. The Other Transportation sector LQ is higher in the U.S. than in Korea and China, but in terms of shipbuilding, the LQ will be the highest in Korea. The analysis for such refinement should follow as a future research agenda.

Table 8.1. Hamilton Industry LQ Comparison across Five Economies

Industry Sector	USA	China	Japan	Korea	Taiwan
Computer & Electronics	0.98	1.57	0.97	4.68	8.93
Electrical Equipment	0.45	2.07	1.80	2.21	1.32
Motor Vehicles	0.59	1.37	1.74	1.83	0.77
Fabricated Metals	0.76	1.46	0.97	1.89	1.79
Machinery & Equipment	0.59	1.81	2.14	1.75	1.19
Chemicals	0.76	1.70	0.97	1.74	1.90
Basic Metals	0.33	2.63	1.44	1.36	1.34
Other Transportation	1.53	0.81	0.71	1.27	1.31
IT and Information Services	1.46	0.57	1.05	0.84	0.48
Pharmaceuticals	1.10	1.05	0.99	0.63	0.33
Overall Composite	0.87	1.47	1.29	1.88	2.12

The benefit of the cross-sector production collaboration will be the mutual scale-up and strengthening of the weak sectors. Thus, the higher the complementarity of the chosen sectors among the production alliance, the more effective such collaboration will be. The LQ distance which can be calculated from Table 8.1 can give reference information as a starting point of this consideration.

A much bigger benefit would arise when this LQ scale-up transforms into innovation improvement. We observed such a possibility from the very high correlation between the overall LQ score and the overall GII score. The magnitude of such a possibility may differ across industries. It turns out that the industry LQ is highly correlated with the innovation index for some industries but not for the other. Ordering the industry sectors by the size of the correlation coefficients between the industry LQ and GII in log scale, it goes as follows: Machinery & Equipment (0.674), Other Transportation (0.619), IT and Information Services (0.618), Pharmaceuticals (0.527), Computer & Electronics (0.520), and Fabricated Metals (0.508). The four sectors of Electrical Equipment, Chemicals, Motor Vehicles, and Basic Metals have no significant correlation between LQ and GII. There are seven categories of GII, and some of them are about "input" components of innovation. Perhaps we need to consider only the "output" components of innovation. Thus, we did a similar analysis using only the output components of GII, such as the "Knowledge and technology outputs" index and the "Creative outputs" index. We do find the same results. The set of sectors with significant correlation remains the same, whether we use the overall GII or the innovation output indices. In fact, the correlation becomes stronger between industry LQ and each of these innovation output indices. Furthermore, the LQ-innovation correlation becomes significant in Electrical Equipment when we use the "Knowledge and technology outputs" innovation index.

By comparing the NISs of the five economies, our study beacons the directions of the policy and institutional reforms of innovation for each nation. Many of them are about domestic measures. We also present a possibility of improving national innovation by forming an effective international alliance for innovation by extending the idea of "comparative advantage" to the collaboration of production utilizing the cross-country differences in production structure and also by linking the international production collaboration to the promotion of innovations. This can be a future direction of designing a better NIS for each nation at the age of global specialization of productions when the idea production and product production tend to be separated across countries, and the vulnerability of economic security from the global dependence of supply chains becomes intensified. The macro-institutional framework and the micro-implementation policy tools to realize such *an innovation alliance* would be found in the active dialogues between the authorities concerned and experts from the potential countries of interest.

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