China' s Path to Becoming a World Science and Technology Power: A Postprint Analysis of Key Indicators from the National Innovation Index Report

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Abstract

The report of the 19th National Congress of the Communist Party of China has inaugurated a new journey for China toward becoming a world science and technology powerhouse. This article, from the perspective of science and technology indicator research, systematically examines the existing weaknesses and development potential in China' s construction of a science and technology powerhouse. It identifies that in the near term, China' s scientific and technological innovation development should prioritize increasing R&D funding investment across society, particularly intensifying enterprise R&D investment, enhancing national higher education talent cultivation, and strengthening international patent application capabilities. From a medium- to long-term perspective, it is essential to address the strategic demands of science and technology powerhouse construction by strengthening both the quality and efficiency of scientific and technological human capital investment and research output, improving labor productivity and energy output rates, thereby realizing the developmental objective of transitioning from being scientifically and technologically strong to becoming a comprehensively strong nation.

Full Text

Analysis of Key Indicators for Construction of China' s World Science and Technology Power—Based on the National Innovation Index Report

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Abstract

The report delivered at the 19th National Congress of the Communist Party of China initiated a new journey toward building China into a world science and technology power. This paper examines the shortcomings and development potential in China' s quest to become a science and technology powerhouse from the perspective of science and technology indicators. It identifies that in the near term, China's scientific and technological innovation development must focus on increasing R&D expenditure across society, particularly the intensity of business enterprise R&D investment, improving national higher education and talent cultivation, and strengthening international patent applications. In the medium to long term, it is essential to address the strategic demands of building a science and technology power by intensifying investment in scientific and technological human resources and improving the quality and efficiency of research output, thereby enhancing labor productivity and energy output efficiency to realize the transition from being strong in science and technology to being a comprehensively strong nation.

Keywords: science and technology power, key indicators, science technology and innovation, development shortcomings

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1. Introduction

Innovation is the primary driver of development and the strategic support for building a modern economic system. The report delivered at the 19th National Congress of the Communist Party of China outlined a blueprint for China to become a world science and technology power and achieve the goal of a modern socialist country. It not only proposed the major strategic policy of building an innovative country but also clarified that innovative country construction must provide strong support for building China into a science and technology power and other powerful nation objectives [1]. This represents a further mobilization and overall deployment of the "three-step" strategy for building a world science and technology power proposed in the *National Innovation-Driven Development Strategy Outline*. Currently, as China works toward the strategic goals set by the Party and state—entering the ranks of innovative countries by 2020, joining the forefront of innovative countries by 2035, and becoming a world science and technology power by 2050—its scientific and technological innovation development has entered a critical stage [2]. How to objectively understand the gaps between China' s scientific and technological innovation development and world science and technology powers, and to identify potential areas for improvement, holds significant implications for accelerating the construction of an innovative country and a science and technology power.

To date, academic research on science and technology powers has largely adopted a systems theory perspective, examining the elements, capabilities, environments, and network relationships required for national science and technology power construction from different dimensions of the national innovation system [3]. Scholars have frequently analyzed the historical experiences of world science and technology powers [4] and studied the science, technology, and innovation development strategies of major countries. However, current research has not yet effectively provided quantitative explanations for the direction and path of China' s transition from scientific and technological innovation to a science and technology power. Based on findings from the *National Innovation Index Report*, this paper identifies existing shortcomings in China' s journey toward building a science and technology power and points out the near-term and medium-to-long-term directions for China' s scientific and technological innovation development through analysis of indicator development trends and potential.

2. Overall Assessment of China' s Innovation Capability Development Level

Accelerating the construction of an innovative country requires a scientific understanding and assessment of China' s innovation capability development level and stage. Through continuous refinement, the connotation and extension of innovation have been enriched to encompass comprehensive innovation including scientific and technological innovation, institutional innovation, management innovation, and business model innovation, with scientific and technological innovation as the core—the strategic support for enhancing social productivity and comprehensive national power. Innovation-driven development uses scientific and technological innovation combined with comprehensive innovation in institutions, management, business models, and industries to promote a shift in development modes toward reliance on continuous knowledge accumulation, technological progress, and improved labor quality, fostering economic evolution toward more advanced forms, finer division of labor, and more rational structures, thereby realizing a new development path from being strong in science and technology to being strong in industry, economy, and nation. Therefore, national innovation capability evaluation must comprehensively reflect the input-output capacity of scientific and technological innovation, enterprise innovation capability, improvement of the innovation environment, and resulting economic and social performance.

Based on systematic research of innovation capability evaluation theories and methods, the Chinese Academy of Science and Technology for Development has conducted innovation index research and continuously published seven issues of the *National Innovation Index Report* since 2011. The national innovation index ranking has become one of the important indicators for judging China' s innovative country construction progress. Drawing on domestic and international theories and methods regarding national competitiveness and innovation evaluation, the report constructs a national innovation index indicator system comprising five dimensions—innovation resources, knowledge creation, enterprise innovation, innovation performance, and innovation environment—with 30 basic indicators, to comprehensively evaluate the innovation capabilities of 40 countries worldwide (whose total R&D investment accounts for 95% of the global total) [5]. Evaluation results show that China' s national innovation index ranking gradually rose from 38th place in 2000 to 17th place in 2017. China' s scientific and technological innovation has undergone profound, comprehensive, and structural changes, with the scale of science and technology resource inputs ranking among the world' s top, innovation output capacity leading globally, and China becoming an important pole in the world innovation landscape—potentially the only developing country to enter the ranks of innovative countries. However, it must be clearly recognized that China faces the problem of being large but not strong, with significant gaps compared to countries such as the United States, Japan, and Germany.

Through systematic analysis of data from the 30 basic indicators in the *National Innovation Index Report*, China' s innovation capability indicators demonstrate three types of performance: (1) Leading indicators—those where China already ranks among the world' s top, such as R&D expenditure scale, domestic patent output, and knowledge-intensive industry development; (2) Indicators with growth momentum and potential for rapid improvement in the short term that can support entry into the ranks of innovative countries and the forefront of innovative countries; and (3) Relatively lagging indicators with large gaps compared to developed countries that require long-term efforts to improve. In response to these three types of indicator performance, China' s scientific and technological innovation work requires targeted deployment. For leading indicators, China must maintain relative advantages and leverage their guiding role. For indicators with potential for rapid improvement, they should become the focus of near-term scientific and technological innovation work to effectively support China' s entry into the ranks of innovative countries and the forefront of innovative countries. For indicators with large gaps, acceleration is needed to make them medium-to-long-term work directions, laying a solid foundation for building China into a world science and technology power by the mid-21st century.

3. Near-Term Priorities for Innovation-Driven Country Construction

3.1 National R&D Expenditure Intensity Research and development (R&D) expenditure reflects a country' s innovation resource input and overall state of innovation activities, and its intensity (R&D expenditure/GDP) is a core indicator for measuring national innovation capability. This indicator not only reflects the intensity of scientific and technological innovation funding input but also effectively measures the integration of science and technology with the economy and the transformation of development modes. In recent years, as innovation has become the country' s primary development concept, China' s national R&D expenditure intensity has rapidly increased [Figure 1: see original paper]. In 2000, China' s R&D expenditure/GDP ratio was 0.89%, less than 1%; it rose above 1% in 2002, broke through 2% in 2014, and continued to climb to 2.11% in 2016 [6]. China' s R&D expenditure/GDP ranking among the 40 countries worldwide rose from a relatively low 29th place in 2000 to 14th place in 2016.

Comparison with major world innovative countries reveals that China still has certain gaps in R&D expenditure intensity. The United States, Japan, and Germany have maintained high levels of R&D expenditure intensity for many years, consistently above 2.5%. Austria, Finland, Sweden, and Switzerland have reached about 3%. Israel has maintained its R&D expenditure/GDP ratio at around 4% since 2000. China' s neighbor South Korea has shown outstanding performance, with its R&D expenditure/GDP ratio continuously climbing from 2.18% in 2000 to over 4.2% in 2014–2016. From a development trend perspective, the growth rate of China' s R&D expenditure/GDP has slowed, and due to its late start, it has only recently entered the high R&D investment stage. Examining the R&D investment development trajectories of different countries, China' s current R&D investment level is equivalent to that of the United States around 1960, Japan around 1980, and South Korea around 1994. Thus, to meet the target requirements of building a science and technology power, China' s R&D expenditure intensity needs further improvement.

From a development trend perspective, China' s R&D expenditure intensity is still in a relatively rapid growth phase compared to other countries, and its international ranking will continue to improve. Although China' s R&D expenditure growth rate has gradually declined from over 20% during the 11th Five-Year Plan period to about 10% since the 12th Five-Year Plan period, it remains far higher than that of the United States, Japan, and Europe. In 2013, China' s total R&D expenditure surpassed Japan' s, making it the world' s second-largest R&D investor. The gap with the United States has rapidly narrowed, increasing from less than 10% of U.S. R&D expenditure in 2005 to 46.2% in 2016 [Figure 2: see original paper]. Currently, as China transitions from high-speed growth to high-quality development and its economy enters a new normal, the in-depth implementation of the national innovation-driven development strategy will further narrow the gap in R&D expenditure intensity with developed countries, providing important support for building a science and technology power.

3.2 Enterprise R&D Expenditure Intensity Enterprises are the main actors in technological innovation, and the scale and level of their R&D investment directly reflect a country' s technological innovation capability, level, and competitiveness. Since the reform of the science and technology innovation system and mechanism in the 1990s, China has basically established an enterprise-centered innovation system framework, with enterprises' dominant position in the national innovation system continuously consolidated. However, compared with countries such as the United States, Germany, Japan, and South Korea, China' s enterprise R&D expenditure intensity is relatively low, and enterprise innovation competitiveness remains weak. According to OECD data, China' s enterprise R&D expenditure intensity (the ratio of enterprise R&D expenditure to value added) was 2.16% in 2016, an increase of about one percentage point from 2005. China' s ranking in enterprise R&D expenditure intensity rose from 25th place in 2005 to 15th place in 2017 [7]. Despite significant improvement, this is still only about 60% of that of the United States, Japan, and Germany, and 2.67 percentage points lower than South Korea [Figure 3: see original paper]. The proportion of Chinese enterprises engaged in innovation activities is also relatively low. According to enterprise innovation survey data from various countries, the proportion of Chinese enterprises with innovation activities is about 39.1%, lagging behind Switzerland' s 75.3%, Germany' s 67%, and Japan' s 48% [8]. This indicates that Chinese enterprises still have considerable gaps in innovation awareness and capability.

With rising labor costs, increasing raw material prices, and competitive pressure from international intellectual property protection, enterprises have gradually recognized the critical role of innovation in enhancing their competitiveness and have continuously increased investment in scientific and technological innovation. China' s enterprise innovation will gradually shift from technology introduction and market capture through business model innovation to independent R&D and market development through technological innovation, effectively supporting innovative country construction. According to the European Commission' s *EU Industrial R&D Investment Scoreboard* , the number of Chinese enterprises making large-scale R&D investments is rapidly increasing. In 2016, 376 Chinese enterprises entered the world' s top 2,500 R&D investors, second only to the United States' 822 enterprises and a substantial increase from 199 enterprises in 2013.

3.3 Higher Education Enrollment Rate Innovation-driven development is essentially talent-driven development, and a high-level talent cultivation system is an important guarantee for building a science and technology power. The higher education enrollment rate reflects a country' s capacity to cultivate scientific and technological human resources and its overall national quality. China' s higher education enrollment rate increased from 19.3% in 2005 to 42.7% in 2016, demonstrating remarkable progress in higher education development. However, compared with major innovative countries, China still lags in higher education and scientific talent cultivation [Figure 4: see original paper]. Switzerland, the United Kingdom, Germany, and Japan have higher education enrollment rates around 60%, while the United States and South Korea are higher at 85% and 93%, respectively.

From a historical perspective, China' s higher education entered a rapid development phase in the 21st century, with the enrollment rate accelerating. Since 2008, China' s higher education enrollment rate has increased rapidly, rising from about 20% to 30% in 2013 and then surging to 42.7% in 2016. According to China' s education development plan, by the end of the 13th Five-Year Plan period in 2020, China' s higher education enrollment rate will increase to 50%, with significantly enhanced overall educational strength and international influence, propelling China into the ranks of human resource and talent powerhouses. It is foreseeable that China' s higher education will maintain rapid development, providing high-quality talent resources for building a science and technology power.

3.4 "Triadic Patents as Share of World Total" and "PCT Patent Applications per 10,000 Enterprise Researchers" In recent years, China' s patent output has surged dramatically, ranking first worldwide in both domestic invention patent applications and grants, and third in the number of valid invention patents. However, in today' s globalized era, a science and technology power' s status depends on its position in the global innovation value chain. The number of triadic patents and PCT patent applications are important indicators reflecting a country' s technological innovation international competitiveness. Triadic patents refer to a single invention patent applied for at the European Patent Office (EPO), the Japan Patent Office (JPO), and the United States Patent and Trademark Office (USPTO). PCT patent applications refer to international patent applications submitted through the Patent Cooperation Treaty, which provides applicants with a more convenient pathway to apply for patents in multiple countries.

The distribution of triadic and PCT patents shows that high-quality core technology patents are concentrated in the United States and Japan [FIGURE:5 and FIGURE:6]. Since 2005, Japan' s share of triadic patents has remained above 30% of the world total, reaching a peak of 37% in 2010 before declining to 31.5% in 2015. The United States' share has remained around 25%, reaching 26.7% in 2015. Although China' s share of triadic patents increased from 0.85% in 2005 to 5.63% in 2015, it is still only about one-fifth that of Japan and the United States. The number of PCT patent applications per 10,000 enterprise researchers reflects the international competitiveness of enterprise technological innovation. China' s PCT applications per 10,000 enterprise researchers increased from 36 in 2005 to 411 in 2016, narrowing the gap to about 71% of the United States, 53% of Germany, and 44% of Japan.

Comparing development trends among the United States, Japan, Germany, and China shows that since 2005, China' s triadic patent numbers have maintained rapid growth, reaching 3,084 in 2015—nearly six times the 2005 figure, with an average annual growth rate of 19.4% over the decade. Conversely, the United States, Japan, and Germany have experienced declining triadic patent numbers, with average annual growth rates of -0.9%, -1.7%, and -4%, respectively, from 2005–2015. Meanwhile, China's PCT patent applications have also far outpaced those of the United States, Japan, and Germany, with an average annual growth rate of 29.5% from 2005–2016, far exceeding Japan' s 5.6% and the below-2% rates of the United States and Germany. It is projected that China' s triadic patent numbers will soon surpass Germany' s and continue narrowing the gap with the United States and Japan, while its PCT patent applications will exceed Japan' s and close the gap with the United States.

4. Medium- and Long-Term Directions for China’ s Science and Technology Power Construction

4.1 Science and Technology Human Resource Input Intensity Talent resources are the primary resource. The number of R&D personnel per thousand population not only measures a country’ s investment in scientific and technological innovation but also reflects the structure of its employed population and represents an important manifestation of social innovation vitality. In contrast, China still lags in the intensity of science and technology human resource input. In 2016, China had 2.81 R&D personnel per thousand population, an increase of 1.8 from 2005 [Figure 7: see original paper]. However, due to the large gap, China’ s ranking has improved slowly, reaching 33rd place in 2016, up only two places from 2005. China’ s science and technology human resource input is less than half that of the United States and Japan and about one-third that of Switzerland, South Korea, and Germany. Preliminary calculations based on recent growth trends of China’ s R&D personnel and population indicate that by 2035, China’ s R&D personnel per thousand population will reach 5, still below the U.S. level in 2016.

As the world’ s most populous country, fully tapping into the role of scientific and technological talent—this primary resource—is crucial for building a science and technology power. In the future, China must implement the talent priority development strategy as outlined in the *National Innovation-Driven Development Strategy Outline*, consistently placing talent resource development at the top priority of scientific and technological innovation. It must strengthen coordination between talent cultivation and utilization systems, optimize talent structure, and strive to cultivate a large-scale, rationally structured, and high-quality innovative scientific and technological talent workforce to provide strong support for accelerating innovative country construction and achieving the goal of becoming a science and technology power.

4.2 Researcher Scientific Paper Output Efficiency Basic scientific research results are an important source of knowledge supply for scientific and technological innovation. The number of scientific papers per 10,000 researchers reflects a country’ s knowledge output efficiency. In recent years, as China’ s scientific paper output has rapidly increased, China’ s SCI paper count has ranked second worldwide for eight consecutive years, continuously narrowing the gap with the United States. However, in terms of researcher scientific paper output efficiency, China’ s number of international scientific papers per 10,000 researchers is not only far below that of Europe, the United States, and Japan but even lower than India’ s. In 2016, China published 1,820 international scientific papers per 10,000 researchers, about three times the 2005 figure, but only one-quarter that of Switzerland (the most efficient) and 60% that of the United States [Figure 8: see original paper]. China’ s ranking among the 40 countries has consistently lagged, placing 36th in 2016, up only three places from 2005. Additionally, the average citation count of China’ s SCI papers remains below the world average.

A strong basic science foundation is the cornerstone of building a world science and technology power. Chinese researchers' performance in scientific paper output reflects China' s relatively low efficiency in knowledge supply for scientific and technological innovation and insufficient personnel investment in basic scientific research. In the future, China must strengthen systematic deployment of basic research, target world science and technology frontiers, deepen science and technology system reform, promote integration of basic research, applied basic research, and technological innovation, and focus on achieving major breakthroughs in forward-looking basic research and leading original achievements to comprehensively enhance innovation capabilities and serve the construction of an innovative country and world science and technology power.

4.3 Labor Productivity Labor productivity, measured as GDP per employed person, reflects the economic development effectiveness and macro-level impact of a country' s scientific and technological innovation activities. It is a 标志性 indicator determining whether a country' s economy has future growth potential and embodies the ultimate effect of transitioning from being strong in science and technology to being strong in the economy. From 2005–2016, China' s labor productivity increased from $3,000 to $14,000 per person, with an average annual growth rate of 15.1% [Figure 9: see original paper]. During the same period, the average annual growth rates of labor productivity in the United States and Switzerland were 2.6% and 2.9%, respectively, Germany' s was 0.8%, and Japan' s was only 0.2%. Luxembourg, with the world' s highest per capita GDP, had an average labor productivity growth rate of 1.5%. Thus, in terms of its own growth rate, China' s labor productivity improvement far exceeds that of major developed countries. However, due to China' s large population, its absolute labor productivity level remains far below these countries. In 2016, China' s labor productivity was only one-fifth of Japan' s, one-ninth of the United States' , and about one-tenth of Luxembourg' s and Switzerland' s. This indicates that China' s labor productivity will remain in a relatively backward state compared with Europe and the United States for a long time.

High economic output efficiency is the proper meaning of a science and technology power. In the future, as China' s economy shifts to medium-high speed growth, it must comprehensively accelerate the transformation of economic development modes and industrial upgrading, focus on improving labor quality, further develop the demographic dividend of quality, and shift economic development from low-cost labor advantages to scientific and technological innovation advantages. It must improve labor productivity through scientific and technological progress, accelerate the pace of technological, management, and institutional innovation, further promote "mass entrepreneurship and innovation," continuously enhance independent innovation capability and core competitiveness, and promote China' s manufacturing industry to move up the global value chain toward the medium-high end, achieving the transformation from

"Made in China" to "Created in China." Simultaneously, it must comprehensively strengthen the rule of law and intellectual property protection, adjust policies to increase returns on R&D investment, and substantially improve comprehensive output efficiency across society to support the nation' s transition from being strong in science and technology to being strong in economy.

4.4 Energy Output Efficiency per Unit Energy is the most important resource element for human civilization and social development, and major scientific and technological innovation transformations are inevitably accompanied by energy technology improvements and replacements. Therefore, efficient energy output efficiency is an essential requirement for a science and technology power. At the macro level, energy output efficiency can be measured by GDP output per kilogram of standard oil equivalent energy consumption, reflecting the effect of technological innovation in reducing energy consumption and demonstrating the intensive level of national economic and social development.

The *National Innovation Index Report* uses World Bank data to calculate that from 2005–2015, China' s economic output per unit of energy consumption increased from $1.3 to $3.6 per kilogram of standard oil equivalent, with an average annual growth rate of 10.8% [Figure 10: see original paper]. During the same period, Switzerland' s average growth rate of economic output per unit of energy consumption was 5.7%, the United States' was 3.9%, the United Kingdom' s was 3.5%, Germany' s was 2.5%, and Japan' s was only 1%. China' s improvement rate far exceeds that of major developed countries. However, in absolute terms, China still has a huge gap and relatively extensive energy consumption. In 2015, China' s energy output efficiency was only about 40% that of the United States and Japan, about 20% that of the United Kingdom, and less than 15% of Switzerland' s [10]. This indicates that China must make enormous efforts in the energy sector to build a science and technology power.

Green development is one of the important concepts for China' s new-era development. China must target the goal of building a science and technology power, aim at international energy technology development trends, give full play to scientific and technological innovation' s leading role in comprehensive innovation, emphasize the establishment and improvement of a green energy technology innovation system, improve energy technology innovation capability and equipment manufacturing levels, strengthen independent energy innovation capability, and enhance the international competitiveness of the energy industry.

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Note: Figure translations are in progress. See original paper for figures.