National Science and Technology Competitiveness: Measurement, Evolution, and International Comparison (Postprint)

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Abstract

Evaluation of national science and technology competitiveness contributes to characterizing the international science and technology competition landscape and provides decision-making references for science and technology policy and strategic development. This article proposes a three-dimensional measurement framework of "potential-effectiveness-capability" for national science and technology competitiveness from an "input-process-output" perspective, achieving a multi-dimensional and whole-process analysis of national science and technology competitiveness measurement that accounts for differences in both scale and efficiency. Based on the "National Science and Technology Competitiveness Report 2023" completed by the authors' research, this article measures the science and technology competitiveness of 34 major countries worldwide, with a focused analysis on the evolution trends of science and technology competitiveness of 11 typical countries including China from 2011 to 2022. Building upon this, a classified analysis of the science and technology competitiveness of the 34 major countries is further conducted from three dimensions—science and technology competition potential, science and technology competition effectiveness, and science and technology competition capability—thereby characterizing the science and technology competition pattern of the 34 major countries and revealing the current status of China' s science and technology competitiveness. The study finds that the growth rate of China' s science and technology competitiveness has gradually slowed in recent years, transitioning to a stage of steady growth, though there remains considerable room for improvement compared with leading science and technology nations. Specifically, China' s level of science and technology competition capability is relatively high; however, compared with major science and technology powers, there exists a substantial gap in the level of indicators reflecting the quality of science and technology outputs. The level of science and technology competition potential has demonstrated remarkable

progress, yet China still exhibits a considerable gap with major science and technology powers in the level of efficiency-type indicators. The level of science and technology competition effectiveness is significantly lower than that of major science and technology powers, representing the most critical factor constraining the overall enhancement of China' s science and technology competitiveness level. Finally, the article proposes countermeasures and recommendations for improving China' s science and technology competitiveness.

Full Text

Preamble

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Abstract

Evaluating national science and technology (S&T) competitiveness helps to characterize the international S&T competition landscape and provides decision-making references for S&T policy and strategic development. This study proposes a three-dimensional measurement framework of "potential-efficiency-strength" for national S&T competitiveness from an "input-process-output" perspective, enabling a multi-dimensional, whole-process analysis that accounts for differences in both scale and efficiency. Based on *The Report on National Science and Technology Competitiveness 2023* completed by the authors, this paper measures the S&T competitiveness of 34 major countries worldwide and focuses on analyzing the evolution trends of 11 typical countries, including China, from 2011 to 2022. Furthermore, it conducts a classified analysis of the S&T competitiveness of these 34 countries from three dimensions—S&T competitiveness potential, S&T competitiveness effectiveness,

and S&T competitiveness strength—to characterize the S&T competition pattern and reveal the current status of China' s S&T competitiveness. The findings indicate that China' s S&T competitiveness growth rate has gradually slowed in recent years, transitioning to a stage of steady growth, though there remains substantial room for improvement compared to leading S&T nations. Specifically, China' s S&T competitiveness strength is relatively high, but its indicators reflecting output quality lag far behind those of major S&T powers. China' s S&T competitiveness potential has improved significantly, yet substantial gaps remain in efficiency-type indicators compared to major S&T powers. The level of China' s S&T competitiveness effectiveness is substantially lower than that of major S&T powers, representing the most critical factor constraining the overall improvement of China' s S&T competitiveness. Finally, the paper proposes policy recommendations for enhancing China' s S&T competitiveness.

Keywords: national science and technology competitiveness, multi-dimensional comprehensive measurement, international comparison
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1. Evolution and International Comparison of China' s Science and Technology Competitiveness

This study selects 11 typical countries for comparative analysis of China' s S&T competitiveness, including six major S&T powers and five BRICS nations. This section presents changes in the S&T competitiveness index and rankings of these 11 countries from 2011 to 2022, analyzing their relative positions. It further examines China' s performance in detail across the three secondary indicators –S&T competitiveness potential, S&T competitiveness effectiveness, and S&T competitiveness strength—compared with other typical countries to understand China' s advantages and disadvantages.

1.1 China' s S&T Competitiveness Has Shifted to Steady Growth, Yet Substantial Gaps Remain with Leading Nations

Overall, the S&T competitiveness index values of the 10 typical countries (excluding China) have risen slightly, remaining generally stable [Figure 2: see original paper]. China' s S&T competitiveness index has increased significantly, but considerable room for improvement remains compared to leading S&T nations. The 11 typical countries can be broadly divided into three tiers based on their S&T competitiveness index values: the United States and Japan, whose index values far exceed others and maintain substantial leads, constitute the first tier; China, Germany, South Korea, the United Kingdom, and France, with relatively high index levels and upper-middle rankings, form the second tier; and the four BRICS nations (excluding China)—Brazil, India, Russia, and

South Africa—show significant gaps from the aforementioned countries and rank in the middle-lower range, representing the third tier.

China's S&T competitiveness has grown rapidly over the 12-year period, moving from the bottom of the second tier to the forefront. Its index value increased from 11.04 in 2011 to 28.46 in 2022, with its ranking rising from 12th to 5th place, surpassing France, the United Kingdom, and South Korea, and ranking just behind Germany within the second tier.

China' s S&T competitiveness development has transitioned from a high-speed growth phase to a steady growth stage. The growth rate of China' s S&T competitiveness index peaked at 18.26% in 2015 and has declined annually since, with stagnation emerging in the last three years, marking a new growth phase. Specifically, since 2015, the growth rates of all three dimensions—S&T competitiveness potential, effectiveness, and strength—have gradually slowed, with growth rates falling below 10% in 2021 and 2022, lower than historical levels. The decline in China' s S&T competitiveness effectiveness index over the past three years represents the primary reason for the stagnation in China' s overall S&T competitiveness level.

1.2 China's Low S&T Competitiveness Effectiveness Constrains Overall Improvement

The S&T competitiveness effectiveness index values of the six major S&T powers have remained stable over the long term, with rankings declining slightly but consistently remaining in the upper-middle range among the 34 countries [Figure 3: see original paper]. In 2022, Japan, Germany, the United Kingdom, France, South Korea, and the United States ranked 4th, 10th, 15th, 20th, 12th, and 14th, respectively, in S&T competitiveness effectiveness. Among the five BRICS nations, Brazil, Russia, and India exhibit low S&T competitiveness effectiveness index values, ranking in the lower range among the 34 countries, at 33rd, 34th, and 32nd positions, respectively, in 2022. South Africa' s S&T competitiveness effectiveness has risen steadily, with its index value increasing from 18th place in 2011 to surpass France.

China' s S&T competitiveness effectiveness index growth rate peaked at 22.31% in 2015, after which it began to decline, turning negative in 2020 and beyond —a trend warranting attention. Analysis reveals that the slowdown and recent decline in S&T competitiveness effectiveness growth partly result from China' s 逐年加大科技投入 (year-by-year increase in S&T investment), which has made the relative advantage in input scale larger than that in output scale. In 2022, China ranked 24th in S&T competitiveness effectiveness index, a substantially lower level compared to its S&T competitiveness strength and potential, making low effectiveness the primary constraint on China' s overall S&T competitiveness improvement.

China performs poorly across all sub-indicators comprising the S&T competitiveness effectiveness index. Specifically, in 2022, except for the relatively high

score in the domestic resident patent authorization indicator, China' s scores in all other indicators lag behind those of the six major S&T powers. Particularly, China' s score in intellectual property rights (IPR) royalty income per unit of R&D investment (0.63) is far below traditional S&T powers such as the United States (10.75), Germany (18.64), and Japan (10.72). Similarly, its score in citations per international journal paper (31.96) trails behind France (68.14), Germany (64.96), and Brazil (42.17).

1.3 China' s S&T Competitiveness Potential Has Improved Significantly, Yet Low Efficiency Indicators Constrain Further Enhancement

The United States maintains high investment in S&T R&D activities, emphasizing increased R&D investment to secure its leading position in S&T [Figure 4: see original paper]. The U.S. consistently ranks 1st in S&T competitiveness potential index, with its index value continuing to grow from 46.11 in 2011 to 67.05 in 2022, representing a 45.42% increase. The other five major S&T powers also emphasize R&D investment, maintaining high potential levels and upper-middle rankings. Among the four BRICS nations (excluding China), S&T competitiveness potential index values remain basically stable, but rankings have declined to varying degrees, trending toward the lower range. In 2022, Brazil, India, Russia, and South Africa ranked 29th, 30th, 28th, and 33rd, respectively.

China' s S&T competitiveness potential has improved dramatically during the observation period, rising from the middle to upper ranks globally. Its index value increased from 19.48 in 2011 to 40.46 in 2022, a growth of 107.73%, with its ranking rising from 18th to 7th place, comparable to Germany and surpassing the United Kingdom, France, and Japan. However, China' s S&T competitiveness potential level still has considerable room for improvement compared to high-potential countries like the United States and South Korea.

Low efficiency indicator values represent the key factor constraining the enhancement of China' s S&T competitiveness potential. At the tertiary indicator level, China scores high in total number of researchers (100) in 2022, but scores low in R&D funding per 10,000 people (9.23), researchers per 10,000 people (15.79), and other efficiency-type indicators, far below the levels of the six major S&T powers. Although China' s score in total R&D funding (57.78) is relatively high compared to countries other than the United States, it still lags significantly behind the U.S. (100).

1.4 China' s S&T Competitiveness Strength Is Relatively High, Yet Output Quality Requires Priority Improvement

The distribution of S&T output among nations is extremely unbalanced, with S&T output benefits concentrated primarily in the United States, China, Japan, and Germany [Figure 5: see original paper]. These four countries rank top four among the 34 major countries in S&T competitiveness strength, holding

overwhelming advantages over others. The United States dominates the global S&T competition landscape, consistently ranking 1st in S&T competitiveness strength with continuously growing index values. In 2022, the U.S. S&T competitiveness strength index value was twice that of Japan and three times that of Germany, leading other countries by a substantial margin.

China' s S&T competitiveness strength index growth has gradually slowed but remains significantly higher than that of the six major S&T powers. China surpassed Japan to become 2nd in 2018, with its growth rate dropping below 10% since 2020 but still exceeding that of the United States. The gap between China and the U.S. in S&T competitiveness strength has been continuously narrowing. Additionally, South Korea, France, and the United Kingdom have seen rising S&T competitiveness strength index values with relatively stable rankings, maintaining upper-middle global positions. Brazil, India, Russia, and South Africa have low S&T competitiveness strength index values and middle-lower rankings, placing 18th, 13th, 16th, and 26th, respectively, in 2022.

China remains in a weak position in IP trade among the 34 major countries, with weak S&T accumulation, necessitating focused attention on improving S&T output quality. At the tertiary indicator level, China leads the 34 major countries in international journal paper publications (98.26), domestic resident patent authorizations (100), and PCT patent applications (100) in 2022. The domestic resident patent authorization indicator value exceeds that of the second-ranked United States (49.74) by more than double. However, China' s scores in international journal paper citations (70.96), triadic patent authorizations (32.16), and IPR royalty income (8.90) are relatively low, particularly the IPR royalty income indicator, which is significantly lower than major S&T powers such as France (11.18), Germany (44.97), Japan (39.86), the United Kingdom (18.17), and the United States (99.05).

2. Evolution Analysis of National S&T Competitiveness Patterns

To comprehensively examine countries' performance across pairwise combinations of the three secondary indicators—S&T competitiveness potential, effectiveness, and strength—this section uses rankings from two secondary indicators as coordinate axes. Using the median line between the 17th and 18th ranked countries as the baseline, it divides the 34 major countries into four quadrants. Simultaneously, it selects each country' s per capita GDP as a reference indicator, using bubble size in the visualization to intuitively present the relationship between national economic development levels and S&T competitiveness.

2.1 Analysis of S&T Competitiveness Strength vs. Potential Patterns

In the competitive landscape of S&T competitiveness strength versus potential, countries with lower per capita GDP predominantly occupy Quadrant III, while those with higher per capita GDP appear in Quadrants I, II, and IV [Figure

6: see original paper]. The six major S&T powers consistently remained in Quadrant I from 2011 to 2022, representing high S&T competitiveness strength and high potential. Among BRICS nations, Brazil and South Africa consistently stayed in Quadrant III with low rankings in both strength and potential. India and Russia remained in Quadrant IV throughout 2011–2022, possessing relatively high strength but low potential, with Russia's potential ranking declining from 24th in 2011 to 28th in 2022, indicating further reduced S&T output. China progressed significantly from the edge between Quadrants I and IV to the center of Quadrant I during 2011–2022, gradually consolidating its position as a country with high S&T competitiveness strength and high potential.

2.2 Analysis of S&T Competitiveness Effectiveness vs. Potential Patterns

The combination of S&T competitiveness effectiveness and potential rankings reveals distinct patterns [Figure 7: see original paper]. The six major S&T powers are concentrated in Quadrant I (high effectiveness, high potential) and Quadrant II (low effectiveness, high potential). Among BRICS nations, Brazil and South Africa are located in Quadrant III (low effectiveness, low potential), while India and Russia fall in Quadrant IV (high effectiveness, low potential). China is situated in Quadrant II, indicating high potential but relatively low effectiveness, highlighting the need to improve efficiency in transforming S&T inputs into outputs.

2.3 Analysis of S&T Competitiveness Strength vs. Effectiveness Patterns

The relationship between S&T competitiveness strength and effectiveness shows that the six major S&T powers are distributed across Quadrants I, II, and IV [Figure 8: see original paper]. The United States and Japan, located in Quadrant I, demonstrate both high strength and high effectiveness. Germany, the United Kingdom, France, and South Korea, positioned in Quadrant II, show high strength but relatively low effectiveness. China is situated in Quadrant IV, characterized by high strength but low effectiveness, indicating that while it produces substantial S&T outputs, the efficiency and quality of these outputs require improvement.

3. Recommendations

Based on the above findings, three sets of recommendations are proposed.

3.2.1 Implement a Comprehensive National S&T Competitiveness Enhancement Strategy

Although China' s overall S&T competitiveness level now ranks among the top tier globally, significant gaps remain compared to world S&T powers such as the United States and Japan. At this stage, China's primary S&T development task

is transitioning from catch-up imitation to self-reliance and strength, placing higher demands on the comprehensiveness, systematic nature, foresight, and autonomy of S&T strategy.

1. **Develop a strategic framework for comprehensively enhancing national S&T competitiveness.** Construct a multi-level, multi-dimensional, and multi-faceted comprehensive enhancement strategy for S&T potential, effectiveness, and strength from the perspectives of macro-level guidance, meso-level resource allocation, and micro-level talent cultivation.
2. **Promote integrated development of "industry, S&T, education, and talent."** Adhere to the principle of coordinated development among S&T, education, talent, and industry. Focus on enhancing industrial international S&T competitiveness to accelerate the construction of a strong S&T nation, strong education system, and strong talent pool.
3. **Implement forward-looking S&T strategic layout focused on future frontiers.** Leverage the Central S&T Commission to streamline strategic decision-making and implementation. Conduct periodic strategic foresight analysis to identify S&T development directions, lead the development of strategic emerging industries and future industries, and accelerate the formation of new quality productive forces.

3.2.2 Establish an Efficiency-Oriented S&T Management System and Mechanism

China's S&T competitiveness effectiveness has shown a declining trend in recent years and remains substantially lower than major S&T powers, representing a critical constraint on overall S&T competitiveness improvement. This urgently requires establishing a S&T development and management system adapted to international competition.

1. **Establish an efficiency-oriented S&T resource allocation mechanism.** Build a navigation platform for S&T resource allocation to identify industry technology dynamics and industrial development needs, systematically and scientifically support rational layout of scientific research directions, and enhance the overall effectiveness of S&T investment. Further optimize research funding management and allocation to address issues of overlapping, redundant, and wasteful expenditures, ensuring funds are effectively used for research itself.
2. **Establish a quality- and benefit-oriented S&T achievement evaluation mechanism.** Focus on the substantive contributions and actual value of S&T achievements. Develop evaluation mechanisms centered on achievements' contributions to disciplinary fields, potential to solve social development problems, and capacity to support national development needs.

3. **Advance high-quality development of the S&T talent pool and enhance per capita S&T output.** Attract more outstanding talents to S&T careers, establish a high-level independent talent cultivation system, optimize incentive systems for researchers, expand openness and exchange in S&T talent, and guide researchers to conduct valuable, high-level, internationally-oriented scientific research.

3.2.3 Strengthen International Competition-Oriented S&T Development Strategy

Insufficient international influence of China' s S&T innovation is a key factor constraining overall S&T competitiveness improvement, as evidenced by significant gaps in indicators such as international journal paper citations, IPR royalty income, and triadic patent authorizations compared to major S&T powers. This necessitates strengthening international competition-oriented S&T development strategies.

1. **Transform China's S&T development strategy toward enhancing international influence.** Adjust China' s S&T development strategic layout to focus on improving international competitiveness and influence. Systematically identify new fields and tracks for international competition, use forward-looking S&T strategies to shift China' s research from followership to leadership, and promote the emergence of more major original S&T achievements.
2. **Promote enterprises' internationalized S&T development strategies.** Support enterprises in implementing internationalized S&T development strategies through multiple channels. Encourage enterprises to globally deploy innovation networks related to core technologies, guide enterprises to apply for international patents according to strategic development needs, and accelerate overseas IP layout.
3. **Promote international transactions of S&T achievements through multiple channels.** Enhance technology export capacity by organizing international technology trade forums, cultivating technology export demonstration institutions, and strengthening the cultivation of senior talent in international technology trade. Actively participate in global IP governance, promote the improvement of IP-related international rules and standards, and remove barriers to international transactions of S&T achievements.

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Appendix: Supplementary Data Tables

Supplementary Table 1 National Science and Technology Competitiveness Evaluation System and Data Sources

Primary Indicator	Secondary Indicator	Tertiary Indicator	Data Source
National S&T Competitiveness	S&T Competitiveness Potential	Total number of researchers	World Bank, Clarivate Analytics InCites
		Total R&D funding	World Bank, Clarivate Analytics InCites
		R&D expenditure as % of GDP	World Bank, Clarivate Analytics InCites
		Researchers per 10,000 people	World Bank, Clarivate Analytics InCites
		R&D funding per 10,000 people	World Bank, Clarivate Analytics InCites
		R&D funding per 10,000 researchers	World Bank, Clarivate Analytics InCites

Primary Indicator	Secondary Indicator	Tertiary Indicator	Data Source
	S&T Competitiveness Effectiveness	International journal papers per unit R&D investment	World Bank, Clarivate Analytics InCites
		Citations per international journal paper per unit R&D investment	World Bank, Clarivate Analytics InCites
		Domestic resident patent grants per unit R&D investment	World Bank, WIPO
		Triadic patent grants per unit R&D investment	World Bank, WIPO
		PCT patent applications per unit R&D investment	World Bank, WIPO
		IPR royalty income per unit R&D investment	World Bank, WIPO
		Citations per international journal paper	Clarivate Analytics InCites
	S&T Competitiveness Strength	International journal paper publications	Clarivate Analytics InCites
		International journal paper citations	Clarivate Analytics InCites
		Domestic resident patent grants	WIPO
		Triadic patent grants	OECD
		PCT patent applications	WIPO
		IPR royalty income	World Bank

Note: To ensure indicator availability, cross-country comparability, and statistical objectivity, data from the World Bank, OECD, WIPO, and Clarivate

Analytics InCites were used for evaluation.

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