Innovation in China: Domestic Efforts and Global Integration

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Summary

China's remarkable rise as an international technology and innovation powerhouse comes courtesy of domestic efforts to upgrade its scientific enterprise. The globalization of science has also played a significant role, fostering links between Chinese and international researchers, allowing Chinese students to study abroad, and attracting foreign direct investment to China's research sector. However, as pressures in Western countries to decouple from China mount, the future of China's science, technology, and innovation system faces strong headwinds.

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Key Findings

- China has rapidly ascended to become one of the world's leading nations for scientific research. While observers frequently point to China's measures to boost domestic science as being responsible for this development, international collaboration has been at least equally critical in China's scientific rise.
- There are four pillars of China's domestic efforts to boost science, technology, and innovation. They include implementing state-led innovation strategies, reforms to the science and technology system, increasing funding for research, and improving the education system to increase the pool of scientific talent.
- As important as these domestic efforts have been, global integration has been pivotal to China's scientific development. Foreign direct investment and foreign-backed research centers have been key to China's scientific ascendancy. Moreover, the return of Chinese citizens educated abroad and diaspora Chinese, as well as collaborations between Chinese scientists and peers in foreign countries, have also been crucial to China's growth as a science, technology, and innovation leader.
- Given the historic reliance of China's scientific enterprise on international exposure and integration, geopolitical headwinds present a significant threat. As Western nations seek to de-risk or decouple strategic high-tech sectors from China, new controls on technology transfer threaten to constrict the growth of Chinese science. Moreover, weakening educational ties based on foreigners' fears of elicit technology transfer through student researchers could further damage China's science sector.
- China's science system faces an uncertain future. China may need to rely increasingly on its domestic efforts to sustain momentum towards becoming a leading scientific nation.

Introduction

The progress that China has made in science, technology, and innovation (STI) during the Reform and Opening Up period is remarkable (see Table 1).[1] Its rise to become a global STI power is frequently attributed to its domestic efforts. But it is also undeniable that China has capitalized on the advantages presented by the globalization of research and education. The key to China's STI accomplishments lies in the synergies between its endeavors on both the domestic and international fronts.

TABLE 1

China's key STI indicators

Indicator	Unit	Value	Year
Gross expenditure on research and development (R&D)	Trillion yuan	3.328	2023
R&D expenditure as a percentage of gross domestic product (GDP)	Percent	2.64	2023
R&D personnel	Million person-years (full-time equivalent)	6.35	2022
College graduates from regular higher-education institutions	Million persons	9.67	2022
Postgraduates at master's level	Persons	779,849	2022
PhD graduates	Persons	82,320	2022
Publications in *Science Citation Index* journals	Rank	1	2021
Rank in the Web of Science for most highly cited papers	Rank	2	2022
Patent applications with the Patent Cooperation Treaty	Number of patents	69,610	2023
Global Innovation Index	Rank	12	2023

Sources: *2023 China Statistical Yearbook* and "Statistic Communique of the People's Republic of China on the 2023 National Economic and Social Development, National Bureau of Statistics of China*; Statistical Data of Chinese S&T Papers (2022)*, Institute for Scientific and Technical Information of China; *PCT Newsletter, March 2024* and *Global Innovation Index 2023*, World Intellectual Property Organization.

Domestic Efforts

China's domestic efforts in science and technology have been laid out comprehensively in a number of recent works.[2] These can be briefly summarized in four areas.

Innovation Strategies

The Chinese Communist Party's Central Committee has formulated a series of strategies to strengthen the nation's scientific enterprise, often in conjunction with the State Council, China's cabinet. Beijing has introduced an array of innovation policies and measures covering research, industrial policy, finance, tax, and fiscal dimensions. China's Medium and Long-Term Plan for the Development of Science and Technology (2006–2020), strategic emerging industries, and Made in China 2025 are some notable examples.

Reform of the Science and Technology System

Enormous and continuous efforts have been made to link scientific research and development (R&D) more closely with the economy. Research institutes—including the Chinese Academy of Sciences—and universities have been strengthened and incentivized to achieve practical research breakthroughs.

China's industrial innovation landscape has witnessed some notable developments. These range from the emergence of academic institutional spin-offs early in the reform period to the rise of private enterprises in high-tech sectors later on. Prominent Chinese firms such as Lenovo, Huawei, Baidu, Alibaba, Tencent, BYD, and ByteDance are household names both domestically and abroad. They, along with state-owned enterprises and foreign-invested companies, now collectively contribute over 70 percent of the nation's total R&D expenditure, while the government supplies the other 30 percent. In parallel, national defense-affiliated R&D establishments have undergone corporatization as well, while national defense universities continue to play vital roles in driving forward research.

Funding Research

Reform has brought about transformative changes in the financing of research. The National Natural Science Foundation of China (NSFC) was established in 1986 to support basic and fundamental research. This led gradually to a national system in which NSFC became one of five distinct funding streams that have been created, each serving a specific group of research and innovation activities.[3]

China's gross expenditure on R&D has grown much faster than its gross domestic product (GDP). In 2023, China spent 2.64 percent of its increasing GDP on R&D, just shy of the 2.72 percent spent by the combined countries of the Organisation for Economic Co-operation and Development (OECD), signifying China's ascent into the league of innovation nations.[4]

Talent Development

China's emergence as the world's largest country in terms of researchers (see Table 1) results from several interrelated factors. A significant contributor is the vast scale of its state-run education system, which is also the world's largest in terms of the number of students at the undergraduate, postgraduate, and doctoral levels. This achievement is closely tied to a pivotal decision made in the late 1990s to substantially expand the number of students enrolled in higher education.[5]

The 2020 census revealed a notable increase in the average number of years of schooling among Chinese citizens aged 15 and older, rising from 9.08 years to 9.91 years within a decade. Students and scholars returning from overseas also contributed to this increased educational attainment among working-age Chinese.[6]

Global Integration

As essential as domestic efforts have been, they have been complemented from the beginning of the reform era by international opening and collaboration. Post-1978 China has been receptive to new knowledge, technology, and ideas from abroad. China's population has warmly embraced international collaboration and the cross-border movement of investment and talent. For example, in 2019, over 700,000 Chinese studied overseas, compared to 860 in 1978.[7] These efforts have enhanced the quantity and quality of China's scientific resources.

Foreign Direct Investment and Corporate R&D

The early period of Reform and Opening Up was marked by investment from overseas Chinese, concentrated in labor-intensive industries. During the 1990s, foreign companies infused capital, managerial acumen, and—crucially—technological knowhow into joint ventures in China.

China's accession to the World Trade Organization in 2001 helped the country rapidly elevate its standing among countries attracting foreign direct investment (FDI). With and through FDI, China continued to integrate into global value chains and emerged as a manufacturing hub. Foreign companies leveraged Chinese infrastructure, industrial clusters, and cost-effective labor, whose productivity has continued to improve.[8]

As China's position in the global economy evolved, the government recognized the need to extract more substantial benefits from FDI. Beijing implemented laws and regulations to attract higher-end operations and encourage multinational corporations (MNCs) to set up R&D centers in China. Noticeably, the government also allowed—for the first time—foreign corporations to wholly own these R&D centers. This move was made to assuage concerns among MNCs that their intellectual property rights could be at risk unless they fully controlled their IP under a joint-venture structure. Local governments were proactive in instituting their own policies, usually complementing and enhancing national frameworks to attract foreign corporate R&D centers.

Meanwhile, MNCs have encountered challenges when attempting to tailor their products to the Chinese market. In response, MNCs began exploring strategies to upgrade their China operations, including by establishing technology development centers and R&D facilities.

The confluence of top-down policies and bottom-up initiatives has propelled a transformation in how some of the world's most technologically innovative companies have engaged with China. Once primarily characterized as a manufacturing hub, China has now become a strategic node in the global innovation network, developing new products and services targeting both the domestic and global markets. Corporate R&D centers funded by investors from overseas as well as from Hong Kong, Macau, and Taiwan operating in China numbered 1,800 at their peak in 2017. Although these enterprises also saw their contribution to China's overall R&D expenditure gradually shrink from 16.24 percent in 2010 to 12.08 percent in 2021, their absolute expenditure grew from 114.7 billion to 337.7 billion yuan over that same period.

Students and Scholars Returning from Overseas

As the country started to open up in the late 1970s, the government sought to cultivate a cadre of high-quality scientists and technical personnel from abroad. Indeed, the incipient stages of the open-door policy were intertwined with the phenomenon of Chinese pursuing studies overseas.

The policy toward overseas study has been generally supportive, notwithstanding occasional challenges.[9] Initially, most students were sent by academic institutions or local, provincial or central governments. Eventually, Beijing allowed self-sponsored students to go abroad; these students have accounted for most overseas Chinese students over the last three decades. National imperatives have evolved to turn “brain drain” into “brain gain”—or, at least, to foster “brain circulation” in support of China’s developmental interests.

Efforts have been made by institutions and governments to attract the return of overseas Chinese.[10] Most significant of the programs is the Thousand Talents Program, launched in 2008.[11] It started as a program for full-time returnees and has added a component for part-timers unwilling or unable to return to China permanently. Two years later, a new Young thousand Talents Program was introduced to target emerging young scientists.[12]

China has witnessed an increasing return of its overseas students and researchers. Up to 2019, 6.5 million students had gone overseas to study, while 4.2 million had returned to China—a 64.5 percent rate of return. In 2019 alone, 703,500 Chinese went abroad as students, and 580,300 returned upon finishing their studies, with a rate of return that year of 79.1 percent.

Returnees have contributed greatly to China’s scientific enterprise. For example, in recent years over 12 percent of mainland China’s total scientific publications were published by scientists with overseas experience. The number of publications among the top 10 percent most highly cited by these scientists is also considerably higher than that of their colleagues who had remained in China throughout their careers.[13]

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International Collaboration

International science and technology (S&T) collaboration has significantly raised the level of research in China and helped Chinese science approach the international frontier of research. The share of papers featuring both a Chinese and non-Chinese author among papers with Chinese authorship in *Science Citation* Index journals increased from 22.1 percent in 2010 to 25.8 percent in 2016, with the total number of such papers also on the rise. In 2021, China’s leading partners included the United States, United Kingdom, Australia, Canada, Germany, and Japan.[14]

An early study also suggests the diaspora plays a significant role in China’s participation in international collaboration.[15] International collaboration has helped nurture important fields of research, from molecular biology to nanotechnology.

Dealing with Decoupling

Through domestic efforts and by taking advantage of the benefits offered by globalization, China has been able to develop its STI system in the past four decades under a generally benign international environment. Two-way exchanges with the rest of the world—especially developed countries—have enabled China to be integrated into the global innovation system and become a leader in research and innovation relatively quickly.

This has been put at risk by the sharp escalation in global geopolitical tensions, especially between China and the United States. The United States under the Trump administration began to consider China a "strategic rival," and the Biden administration has erected a "small yard and high fence" to prevent China from getting access to U.S. advanced technologies. The European Union now also views China as an "economic competitor" and "systemic rival," rather than a partner for S&T cooperation.

The United States has levied harsh sanctions against Chinese enterprises and universities by putting them on the Department of Commerce's Entity List to restrict their access to the advanced technology, knowhow, and components. In 2023, the Biden administration introduced new restrictions on investments in China in areas such as semiconductors, quantum technologies, and artificial intelligence systems citing national security concerns. The U.S.-China Agreement on Cooperation in Science and Technology, signed by Jimmy Carter and Deng Xiaoping in 1979 and frequently renewed afterward, ended in August 2022, signaling the end of decades of productive cooperation.

Today, academic collaborations are being challenged for fear of illicit technology acquisition attempts. Foreign scientists have become reluctant to collaborate with their Chinese counterparts. China and the United States had been each other's primary scientific collaborators for decades, but joint publications started to decline in 2020.[16] With the U.S. Department of Justice's now defunct "China Initiative," the U.S. government targeted China's efforts to attract overseas talents under the Thousand Talents Program because of alleged concerns about Chinese spying and intellectual property theft within the U.S. research and high-tech industries. This has not only cut the connections between American and Chinese scientists, but has also driven an increasing number of ethnic Chinese scientists back to their homeland.[17]

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Policy Implications

China's S&T system continues to face daunting challenges. China's leading edge in research is subverted by weakness in other areas. Its research often appears derivative, based on work done in developed countries. Its international patent applications have been rising, but the quantity of patents has not been translated into a qualitative improvement as measured by transnational patents.[18]

China's talent pool is quite strong in terms of both quantity and quality—the latter of which comes from the exposure of workers to international education and research. China is the largest country of origin for temporary visa holders earning doctorates from American universities. But China has seen a large proportion of its nationals with American doctoral degrees chose to remain in the United States post-graduation, although the rate at which Chinese doctoral graduates remain in the United States has declined from 92.5 percent in 2002 to 76.7 percent in 2022.[19] Amid rapidly deteriorating attitudes toward China in the United States and the West in general, ethnic Chinese scientists find themselves confronted with a difficult choice—whether to remain with foreign employers or to repatriate to China.

While publications authored by Chinese returnees from overseas exhibit higher impact compared to those of China-based researchers without overseas experience, a substantial number of published Chinese researchers have relocated to the United States and Europe, suggesting that China may face challenges retaining its best scientists.[20] The decoupling of Chinese students and researchers from international research and education could considerably impede China from becoming a world-leading S&T power.

Finally, there is great dependence on foreign technology in China, whose high-tech sector is vulnerable to foreign technological controls. China still runs a large intellectual property deficit. According to the World Bank, China has increased its payments for the use of foreign intellectual property significantly from $6.63 billion to $44.47 billion between 2006 and 2022, while its receipts for exports of its own IP increased from $200 million to $13.3 billion in the same period.[21] With the United States and its allies working to constrain Chinese access to advanced technologies—including through secondary sanctions on suppliers of non-U.S. origins—there will be adverse consequences for China's scientific research and innovation.

Conclusion

As its international ties become increasingly jeopardized, China must navigate anti-globalization headwinds. Although China is not as autarkic as it was in the early period of the People's Republic, it now must depend more upon itself by doubling down on its domestic efforts in science, technology, and innovation. Given its past reliance on transnational scientific collaboration, this is not a welcome scenario for China. Therefore, it remains to be seen whether China's national STI system is ready to take on the challenges posed by decoupling and perform as well as it did during the first 40 years of Reform and Opening Up. The future, considering these dynamics, seems uncertain.

Endnotes

1. Xiaolan Fu, Bruce McKern, and Jin Chen, eds., *The Oxford Handbook of China Innovation*. Oxford: Oxford University Press, 2021.

2. Denis Fred Simon and Cong Cao, *China's Emerging Technological Edge: Assessing the Role of High-End Talent*, Cambridge: Cambridge University Press, 2009; Yutao Sun and Cong Cao, *The Political Economy of Science, Technology, and Innovation in China: Policymaking, Funding, Talent, and Organization*, Cambridge: Cambridge University Press, 2023.

3. Sun and Cao, *The Political Economy of Science, Technology, and Innovation in China*.

4. "Gross domestic spending on R&D," OECD Data, accessed May 15, 2024, https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm.

5. Simon and Cao, *China's Emerging Technological Edge*; Cong Cao and Denis Fred Simon, "China's talent challenges revisited," in *Innovation and China's Global Emergence*, eds. Erik Baark, Bert Hofman, and Jiwei Qian, (Singapore: NUS Press, 2021), 90–112.

6. "Communiqué of the Seventh National Population Census (No. 6)," National Bureau of Statistics of China, May 11, 2021, https://www.stats.gov.cn/english/PressRelease/202105/t20210510_1817191.html.

7. "Leading Places of Origin – From the 2023 *Open Doors* Report," Institute for International Education, accessed May 23, 2024, https://opendoorsdata.org/data/international-students/leading-places-of-origin/.

8. Denis Fred Simon, and Cong Cao, "Foreign corporate R&D in China: A strategic perspective," in *Routledge Handbook of Chinese Business and Management*, ed. Jane Nolan, (London: Routledge, 2023), 346–370.

9. Simon and Cao, *China's Emerging Technological Edge*.

10. Cong Cao, Jeroen Baas, Caroline S. Wagner, and Koen Jonkers, "Returning scientists and the emergence of China's science system," *Science and Public Policy* 47, no. 2, April 2020, 172–183, https://academic.oup.com/spp/article/47/2/172/5658550.

11. David Zweig and Siqin Kang, *America challenges China's national talent programs*, Center for Strategic and International Studies report, May 5, 2020, https://www.csis.org/analysis/america-challenges-chinas-national-talent-programs.

12. Dongbo Shi, Weichen Liu, and Yanbo Wang, "Has China's Young Thousand Talents Program been successful in recruiting and nurturing top-caliber scientists?" *Science* 379, January 5, 2023, 62–65, https://www.science.org/doi/10.1126/science.abq1218.

13. Cao et al., "Returning scientists and the emergence of China's science system."

14. "Statistical Data of Chinese S&T Papers (in Chinese)," Institute for Scientific and Technical Information of China (ISTIC), 2023, http://conference.istic.ac.cn/meetingmanage/userfiles/2/files/material/a1b3de2b78444399b8fe88703f123f8e/document/1695123797464034826.pdf.

15. Bihui Jin, Ronald Rousseau, Richard P. Suttmeier, and Cong Cao, "The role of ethnic ties in international collaboration: The overseas Chinese phenomenon," in *Proceedings of the ISSI 2007*, eds. Daniel Torres-Salinas and Henk F. Moed, (Madrid: Centre for Scientific Information and Documentation of the Spanish Research Council, 2007), 427–436.

16. Li Tang, "Halt the ongoing decoupling and reboot US-China scientific collaboration, *Journal of Informetrics* 18, 2024, 101521.

17. Yu Xie, Xihong Lin, Ju Li, Qian He, and Junming Huang, "Caught in the crossfire: Fears of Chinese–American scientists," in *Proceedings of the National Academy of Sciences of the United States of America* 120, no. 27, e2216248120, April 18, 2023, https://www.pnas.org/doi/full/10.1073/pnas.2216248120.

18. Ulrich Schmoch and Birgit Gehrke, "China's technological performance as reflected in patents," *Scientometrics* 127, 2022, 299–317.

19. National Science Foundation, *Doctorate Recipients from U.S. Universities in 2004–2022*, Alexandria, VA: National Science Foundation, 2005–2023.

20. Cao et al., "Returning scientists and the emergence of China's science system."

21. "Charges for the use of intellectual property, receipts (BoP, current US$) – China," World Bank, accessed May 23, 2024, https://data.worldbank.org/indicator/BX.GSR.ROYL.CD?locations=CN.

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