February 24, 2023

"China's Challenges and Capabilities in Human Capital for General-Purpose Technologies"

Testimony before the U.S.-China Economic and Security Review Commission
Hearing on China's Challenges and Capabilities in Educating and Training the Next Generation Workforce

Jeffrey Ding
Assistant Professor of Political Science, George Washington University

Introduction

This testimony articulates an important distinction between innovation and diffusion capacity, which is crucial to accurate assessments of national scientific and technological capabilities. In contrast to an innovation-centric approach, an assessment based on diffusion capacity reveals that China is far from being a science and technology superpower. China's efforts to reform its education system will play a pivotal role in its ability to adapt to revolutionary technological advances and sustain economic growth in the long run.

I. Innovation vs. Diffusion Capacity

Discussions about national S&T capabilities tend to center on which state first generates new-to-the-world breakthroughs (*innovation capacity)*. In this testimony, the main point I aim to convey is that estimates of China's S&T capabilities should give greater weight to its *diffusion capacity*, or its ability to spread and adopt innovations, after their initial inception, across productive processes. When there is a substantial disparity between these two facets of a nation's S&T capabilities, innovation-centric assessments of its power to leverage S&T advances for sustained economic growth will prove misleading.[1]

Up front, I want to clarify that my testimony is especially relevant for assessments of a rising power's ability to exploit technological changes and maintain higher economic growth rates than its rivals. Historically, this mechanism has been central to the rise and fall of great powers.[2] My testimony has less bearing on other channels by which states can leverage S&T capabilities for influence, which may also come under the committee's purview. Innovation-centric assessments may be rightly prioritized in such contexts, such as the significance of S&T systems to prestige

[1] This and the following section draw on a forthcoming article: Jeffrey Ding. (2023). "The Diffusion Deficit in Scientific and Technological Power: Re-assessing China's Rise." *Review of International Political Economy*.

[2] Kennedy, Paul M. The Rise and Fall of the Great Powers: Economic Change and Military Conflict from 1500 to 2000. New York: Random House, 1987.

and reputation, control over global supply chains, and military power.[3] Still, appropriate attention to diffusion capacity can better inform other S&T dimensions of state power. For instance, there can be a large disparity between a military's ability to first field advanced military systems and its ability to adopt such systems throughout its branches and subunits.[4]

In many cases, there is not much daylight between a state's diffusion capacity and its innovation capacity. These two parameters can be highly correlated. After all, the state that first pioneered a new method has a first-mover advantage in the widespread adoption of that technique. In addition, absorbing innovations from international sources is difficult without the tacit knowledge embedded in the original context of technological development.[5] Diffusion and innovation are entangled, overlapping processes.[6]

However, in some circumstances, diffusion and innovation capacity can widely diverge. Aside from innovation capacity, many other factors can shape a country's adoption rate of new technologies, including institutions that incentivize technology transfer, trade openness, and human capital.[7] The "advantages of backwardness" sometimes enable laggards to diffuse new technologies faster than the pioneering states.[8] Confronting a world of globalized science and technology flows, even the most advanced economies must be able to intensively absorb and diffuse innovations first incubated in other countries. According to one estimate derived from data on Organisation for Economic Co-operation and Development countries, 93 percent of total factor productivity increases in these high-income countries derive from knowledge that originated abroad.[9]

As a result, diffusion capacity indicators can be better predictors of a state's long-term growth trajectory than innovation capacity indicators. The latter may be more unreliable given the uncertain, protracted pathway between a new technology's introduction and its ultimate impact on productivity growth. To this point, one study found that two standard innovation capacity indicators, R&D intensity and patenting rates, tracked less well with subsequent changes in

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[3] Gilady, Lilach. The Price of Prestige. Chicago: Univ. of Chicago Press, 2017, 55-89; Malkin, Anton. "The Made in China Challenge to US Structural Power: Industrial Policy, Intellectual Property and Multinational Corporations." Review of International Political Economy 0, no. 0 (October 1, 2020): 1–33; Paarlberg, Robert L. "Knowledge as Power: Science, Military Dominance, and U.S. Security." International Security 29, no. 1 (2004): 122–51.
[4] Ding, Jeffrey and Allan Dafoe. (2023). Engines of Power: Electricity, AI, and General-purpose, Military Transformations. *European Journal of International Security*, 1-18.
[5] Fadly, Dalia, and Francisco Fontes. "Geographical Proximity and Renewable Energy Diffusion: An Empirical Approach." Energy Policy 129 (June 1, 2019): 422–35; Keller, Wolfgang. "International Technology Diffusion." Journal of Economic Literature 42, no. 3 (September 2004): 752–82.
[6] Taylor, Mark Zachary. The Politics of Innovation: Why Some Countries Are Better Than Others at Science and Technology. 1st edition. New York, NY: Oxford University Press, 2016.
[7] Comin, Diego, and Bart Hobijn. "An Exploration of Technology Diffusion." American Economic Review 100, no. 5 (December 2010): 2031–59.
[8] Gerschenkron, Alexander. "Economic Backwardness in Historical Perspective (1962)." The Political Economy Reader: Markets as Institutions, 1962, 211–28.
[9] Madsen, Jakob B. "Technology Spillover through Trade and TFP Convergence: 135 Years of Evidence for the OECD Countries." Journal of International Economics 72, no. 2 (July 1, 2007): 464–80.

productivity than indicators of activities related to broadly disseminating information about new products and processes.[10]

When there is a substantial gap between diffusion and innovation capacity, assessments based solely on innovation capacity indicators will be misleading because they undervalue the process by which new advances are embedded into productive processes. Specifically, a "diffusion deficit" characterizes situations when a state has a strong innovation capacity but weak diffusion capacity, which suggests that it is less likely to sustain its rise than innovation-centric assessments depict. For example, innovation-centric assessments overestimated the Soviet Union's scientific and technological capabilities in the postwar period. Taking diffusion capacity seriously would have provided a more balanced assessment of the Soviet Union's scientific and technological capabilities.[11]

II. China's Diffusion Deficit

Is China poised to become a science and technology superpower? Existing assessments of China's S&T capabilities tend to center on its aptitude in generating novel breakthroughs. To warn about challenges to U.S. technological leadership, analysts typically cite China's impressive performance in indicators of innovation capacity, such as R&D expenditures, scientific publications, and patents.[12] Less attention, if any, is paid to China's diffusion capacity. For example, the U.S.-China Economic and Security Review Commission's 2022 report to Congress mentions "innovation" 146 times. The term "diffusion" appears just twice.[13]

Yet, according to my research, China faces a diffusion deficit: its diffusion capacity trails significantly behind its innovation capacity. Similar to issues with evaluating the Soviet Union's S&T ecosystem in the 1970s, this means that conventional assessments overestimate China's S&T capabilities. It is necessary to reorient such assessments toward a diffusion-centric lens, which show that China is far less likely to sustain its rise than innovation-centric assessments suggest.

To analyze whether China's diffusion capacity varies significantly from its innovation capacity, I separated indicators included in the Global Innovation Index, a widely-used benchmark for national S&T capabilities published by the World Intellectual Property Organization, into these dimensions. For example, the GII ranks countries globally by the quality of their top three universities and their top three firms' R&D expenditures. I categorize these as indicators of innovation capacity. The GII also ranks countries by indicators that correlate strongly with a

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[10] Alexopoulos, Michelle. "Read All about It!! What Happens Following a Technology Shock?" American Economic Review 101, no. 4 (June 2011): 1144–79.
[11] For more on this historical case, see Jeffrey Ding. (2023). "The Diffusion Deficit in Scientific and Technological Power: Re-assessing China's Rise." *Review of International Political Economy*.
[12] Kennedy, Andrew B. "Powerhouses or Pretenders? Debating China's and India's Emergence as Technological Powers." The Pacific Review 28, no. 2 (March 15, 2015): 281–302.
[13] U.S.-China Economic and Security Review Commission. "2022 Report to Congress." November 2022.

country's capacity to diffuse new advances, including the extent of linkages between businesses and universities.

This decomposition of the 2020 GII reveals that China's diffusion capacity significantly lags behind its innovation capacity (Table 1). Using the GII's figures, averaging China's global ranking on indicators for innovation capacity gives an average of 13.8. However, if the same exercise is conducted using diffusion capacity indicators, China's average ranking drops to 47.2. For reference, on the innovation capacity subindex, China's score is very close to the U.S.'s average ranking (11.9). As for the diffusion capacity subindex, the gap widens significantly between China's average ranking of 47.2 and the U.S.'s average ranking of 26.9. Table 1 displays the GII indicators used to calculate China's diffusion capacity and innovation capacity.

A close examination of China's adoption of information and communications technologies (ICTs), key drivers of future productivity growth, provides further evidence of China's lethargic diffusion capacity. While China has been successful at large-scale deployment in a few key domains — consumer-facing applications like mobile payments and high-speed rail — these achievements do not characterize the overall trend in ICTs. Chinese businesses have been slow to embrace digitization, as measured by adoption rates of cloud computing, digital factories, industrial robots, smart sensors, and key industrial software.[14] The International Telecommunication Union's ICT Development Index provides a composite measure of the level of access to and use of ICTs in countries around the world. On this metric, China ranks 83rd in the world, which trails the U.S. by 67 places.[15]

III. Education and Technological Advantage

China's investments in human capital will be a significant factor in shaping its future diffusion and innovation capacity. There is some evidence that the Chinese government prioritizes R&D investments, which sometimes trades off other pathways to productivity growth based around technology adoption and broad-based education.[16] The consistency of China's fulfillment of R&D spending targets does not extend to the fulfillment of education funding benchmarks.

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[14] Alibaba Research Institute. "From Connected to Empowered: Smart+ Assisting the High-Quality Development of China's Economy [从连接到赋能：'智能+'助力中国经济高质量发展]," March 11, 2019; Synced [机器之心]. "Market Research Report on Supply and Demand for Digital Intelligentization Solutions for China's Small and Medium Enterprises [中国中小企业数智化解决方案供应市场研究报告 2020]," October 2020; Techxcope [战略前沿技术]. "Innovation Is More than Invention: Detailed Explanation of the German Industry-University-Research Systems' Big Four [创新不止于发明：德国产学研体系四大金刚详解]," November 18, 2020.

[15] International Telecommunications Union. "Measuring the Information Society Report 2017," 2017. https://www.itu.int/en/ITU-D/Statistics/Pages/publications/mis2017.aspx.

[16] Brandt, Loren, John Litwack, Elitza Mileva, Luhang Wang, Yifan Zhang, and Luan Zhao. "China's Productivity Slowdown and Future Growth Potential." Policy Research Working Paper. World Bank Group, June 2020.

A comparison of China with other newly industrialized economies illustrates this point. Based on 2018 data, China's public expenditures on education as a ratio of GDP was lower than the corresponding figure for Brazil, Malaysia, Mexico, and South Africa.[17] By contrast, China's R&D spending as a percentage of GDP far exceeded that of these countries. One possible explanation for this disparity, according to a group of experts on China's science and technology system, is the longer time required for efforts in education policy to yield tangible progress in technological development.[18] Related research has shown that the Chinese government has neglected low levels of upper secondary education attainment, possibly due to the over-reporting of such rates by the Ministry of Education.[19]

In recent years, there has been more scrutiny of China's investments in the human capital necessary to adapt to emerging technologies such as AI. As technology races forward, skills must keep pace. Some studies, including a report by Harvard University's Belfer Center for Science and International Affairs, inflate China's capacity to diffuse AI advances at scale because of its sheer quantity of computer science graduates.[20] Accurately assessing China's current strengths and weaknesses in AI education is an important issue.

General counts of graduates, without accounting for the quality of education, overstate China's capacity to cultivate a broad base of AI engineers. Comparisons of computer science education, in particular, can mislead, if the quality of such training is not considered.[21] Consider one quality baseline for AI education: a university meets this standard if it employs at least one researcher that has published at least one paper in a leading AI conference. According to data from the years 2020-2021, China was home to only 29 universities that met this standard; the U.S. accounted for 159 such universities.[22]

When it comes to disseminating AI advances across the entire economy, robust linkages between academic and industry settings are especially crucial. The U.S. has built a strong connective tissue in this respect. Per data on the years 2015 to 2019, the U.S. was the world leader in the number of academic-corporate hybrid AI publications — publications co-authored by at least one researcher from industry and one researcher from academia. This more than

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[17] Statistics based on the UNESCO Institute of Statistics Database.
[18] Liu, Xielin, Sylvia Schwaag Serger, Ulrike Tagscherer, and Amber Y. Chang. "Beyond Catch-up—Can a New Innovation Policy Help China Overcome the Middle Income Trap?" Science and Public Policy 44, no. 5 (October 1, 2017): 656–69.
[19] Khor, Niny, Lihua Pang, Chengfang Liu, Fang Chang, Di Mo, Prashant Loyalka, and Scott Rozelle. "China's Looming Human Capital Crisis: Upper Secondary Educational Attainment Rates and the Middle-Income Trap." *The China Quarterly* 228 (December 2016): 905–26.
[20] Allison, Graham, and Eric Schmidt. "Is China Beating the U.S. to AI Supremacy?" Belfer Center for Science and International Affairs, August 2020.
[21] Loyalka, Prashant, Ou Lydia Liu, Guirong Li, Igor Chirikov, Elena Kardanova, Lin Gu, Guangming Ling, et al. "Computer Science Skills across China, India, Russia, and the United States." Proceedings of the National Academy of Sciences 116, no. 14 (April 2, 2019): 6732–36.
[22] Analysis based on the CSRankings website. For details on the original methodology, see Tencent Research Institute and Boss Zhipin 2017, 12.

doubled China's number of hybrid AI publications.[23] Indeed, China's official state news agency has highlighted the lack of technical exchanges between universities and industry as one of five key weaknesses in China's AI talent ecosystem.[24]

It is now becoming increasingly common for reports to claim that China has overtaken the U.S. in certain measures of elite research in AI.[25] One important distinction to make is that these claims tend to draw on indicators based on AI publications in *journals*. In fast-moving fields like AI, a country's performance in *conference* publications may be a much better indicator of its high-end talent than journal publication-based indicators. As Stanford University's AI Index pointed out in 2021, "the United States has consistently (and significantly) more AI conference papers (which are also more heavily cited) than China over the last decade."[26]

To be sure, China has made important investments in enhancing AI education. In 2018, the Chinese Ministry of Education approved the creation of an AI major, which was quickly adopted by universities around the country.[27] For instance, a February 2021 survey report on China's computer vision talent found that 7 percent of respondents (which included students in the computer vision field) had studied the new AI major. These initiatives followed from the designation of "AI 2.0", an initiative to significantly boost AI education and development, as one of 16 Megaprojects in 2017.[28] Since many of these efforts will take a long time to bear fruit, it is too early to make definitive conclusions about China's efforts to align its human capital investments with its techno-industrial policy aims in AI.

IV. Conclusion and Policy Recommendations

Given the above analysis of China's diffusion and innovation capacity, the following policy recommendations could help safeguard U.S. interests:

First, keep calm and avoid overhyping China's S&T capabilities. My research suggests that the U.S.'s lead in S&T capabilities over China should endure. This committee receives a lot of

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[23] Zhang, Daniel, Saurabh Mishra, Erik Brynjolfsson, John Etchemendy, Deep Ganguli, Barbara Grosz, Terah Lyons, et al. "The AI Index 2021 Annual Report." Stanford Human-Centered Artificial Intelligence Institute, 2021.

[24] Xinhua. "News Analysis: Examining the Five Shortcomings of China's AI Talent System［新闻分析：透视中国人工智能人才体系五大短板]." Xinhua News Agency, August 28, 2019. http://www.gov.cn/xinwen/2019-08/28/content_5425310.htm.

[25] See, for example, Nikkei Asia. "China Trounces U.S. in AI Research Output and Quality." January 15, 2023. https://asia.nikkei.com/Business/China-tech/China-trounces-U.S.-in-AI-research-output-and-quality.

[26] Zhang, Daniel, Saurabh Mishra, Erik Brynjolfsson, John Etchemendy, Deep Ganguli, Barbara Grosz, Terah Lyons, et al. "The AI Index 2021 Annual Report." Stanford Human-Centered Artificial Intelligence Institute, 2021.

[27] Ding, Jeffrey. "China's current capabilities, policies, and industrial ecosystem in AI." Testimony before the US-China Economic and Security Review Commission Hearing on Technology, Trade, and Military-Civil Fusion: China's Pursuit of Artificial Intelligence, New Materials, and New Energy (2019).

[28] Ding, Jeffrey. "Deciphering China's AI dream." *Future of Humanity Institute Technical Report* (2018).

proactive policy proposals. Sometimes the status quo is a defensible policy option. Techno-industrial policy is a difficult endeavor, and there is a risk that even the most agreeable policy interventions can backfire.

Second, revive the Office of Technology Assessment (OTA). There is a need for more balanced assessments of where China and the U.S. stand with respect to S&T capabilities. The OTA helped fill this gap from 1972 to 1995. There is bipartisan support for this proposal, and both liberal and conservative think tanks have supported proposals to revive the OTA.[29]

Third, invest in technology diffusion. In the context of general-purpose technologies such as AI, policies directed at broadening the AI talent base, such as by further supporting community colleges in developing the AI workforce, may be just as, if not more, important as producing the best and brightest AI experts.[30] The U.S. should also invest in "technology diffusion institutions," such as applied technology centers and dedicated field services, that encourage the adoption of AI techniques by small businesses.[31] All too often, it seems, the U.S. government's go-to recommendation for any strategic technology is to boost R&D spending. A diffusion-oriented perspective demands a more varied approach.

Appendix

Table 1: China's S&T Power: An Innovation-Diffusion Decomposition of the GII

Innovation Capacity Subindex		*Diffusion Capacity Subindex*	
Indicator	China's global ranking	Indicator	China's global ranking
QS university rankings	3	ICT access	71
Gross expenditures on R&D	13	ICT use	53
Global R&D companies	3	University/industry research collaboration	29
Researchers, full-time equiv./mn pop.	48	State of cluster development	25
R&D performed by business	12	GERD financed by abroad	81
R&D financed by business	4	JV strategic alliance deals/bn	76
Patents by origin*	1	Patent families 2+ offices/bn PPP%GDP	27
Patent Cooperation Treaty patents by origin*	15	Intellectual property receipts, % total trade	44
Utility models by origin/bn PPP$ GDP*	1	High-tech net exports, % total trade	5
Scientific & technical articles*	39	ICT services exports, % total trade	61
Citable documents H-index	13		
Average ranking	**13.8**	**Average ranking**	**47.2**

Source: Global Innovation Index 2020, World Intellectual Property Organization 2020. *per billion PPP$ GDP.

[29] Katherine Tully-McManus, "House Members Call for Office of Technology Assessment Revival," Roll Call, April 2, 2019, https://www.rollcall.com/news/congress/house-members-call-office-technology-assessment-revival.
[30] West, Darrell M. *The Future of Work: Robots, AI, and Automation*. Brookings Institution Press, 2018, p. 112-113; National Security Commission on Artificial Intelligence. "Final Report." Washington, D.C.: NSCAI, March 2021. https://www.nscai.gov/2021-final-report/, p. 175.
[31] Shapira, Philip, and Jan Youtie. "The next Production Revolution and Institutions for Technology Diffusion." *The Next Production Revolution: Implications for Governments and Business*, 2017.