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"National security and economic competitiveness implications of AI"

Testimony before the Senate Select Committee on Intelligence

Hearing on Advancing Intelligence in the Era of Artificial Intelligence: Addressing the National Security Implications of AI

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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 scientific and technological (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 evaluations of technological leadership in AI should give greater weight to a state's *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 understanding the global economic competition dynamics surrounding AI, or the ability of states to 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 AI and emerging technologies could influence national security, which may also come under the committee's purview. Innovation-centric assessments may be rightly

[1] This testimony draws from 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.

prioritized in such contexts, such as the significance of S&T systems to prestige 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

[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.

indicators, R&D intensity and patenting rates, tracked less well with subsequent changes in 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 Senate Select Committee on Intelligence's 2022 report on protecting U.S. innovation, which included a lengthy section on China's technological rise, mentions "innovation" or "crown jewels" over ten times . The terms "diffusion" or "adoption" do not appear at all.[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.

Innovation-centric views of China's AI capabilities paint an overly optimistic picture of China's challenge to U.S. technological leadership. Influential reports emphasize China's growing strength in AI-related innovation, backed by indicators on R&D expenditures, leading AI

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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] Senate Select Committee on Intelligence. "Organizational Assessment: The National Counterintelligence and Security Center." September 2022.

startups, and valuable internet companies. Likewise, to supports its warning that China is poised to overtake the U.S. in the capacity to generate new-to-the-world advances in AI, the National Security Commission on AI's final report cites shares of breakthrough papers in AI and investments in startups. These evaluations align with viewpoints that are bullish on China's overall technological capabilities, which also point to similar indicators of innovation capacity, such as R&D expenditures, scientific publications, and patents.

A diffusion-centric perspective, based on a close examination of China's adoption of information and communications technologies (ICTs), paints a different picture. 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 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] China also significantly trails the U.S. in an influential index for adoption of cloud computing, which is essential to implementing AI applications. In 2018, U.S. firms averaged a cloud adoption rate of over 85 percent, more than double the comparable rate for Chinese firms.

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 inflate China's capacity to diffuse AI advances at scale because of its sheer quantity of computer science graduates.[16] 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.[17] 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

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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] Allison, Graham, and Eric Schmidt. "Is China Beating the U.S. to AI Supremacy?" Belfer Center for Science and International Affairs, August 2020.

[17] 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.

home to only 29 universities that met this standard; the U.S. accounted for 159 such universities.[18]

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 doubled China's number of hybrid AI publications.[19] 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.[20]

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.[21] 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."[22]

Lastly, to analyze whether China's overall diffusion capacity in science and technology 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 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

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[18] Analysis based on the CSRankings website. For details on the original methodology, see Tencent Research Institute and Boss Zhipin 2017, 12.
[19] 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.
[20] 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.
[21] 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.
[22] 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.

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.

III. Recent Trends in China's Large Language Model Ecosystem

Over the past few years, Chinese labs have quickly followed in the footsteps of U.S. labs to build large language models (LLMs), text generation systems such as ChatGPT. In a recent *Foreign Affairs* piece, Helen Toner, Jenny Xiao, and I argued that "When it comes to LLMs, China trails years, not months, behind its international competitors." This gap is a product of many factors, including a reliance on Western counterparts to open up new paradigms of AI development, political constraints on free speech, and relative lack of high-quality Chinese-language data for training.

China's pace of LLM development is also impeded by bottlenecks in the supply of semiconductors. In the *Foreign Affairs* article, we laid out this case in detail:

> *Due to the outsized computational demands of LLMs, the international competition over semiconductors inevitably affects AI research and development. The Chinese semiconductor industry can only produce chips several generations behind the latest cutting-edge ones, forcing many Chinese labs to rely on high-end chips developed by U.S. rms. In recent research analyzing Chinese LLMs, we found 17 models that used chips produced by the California-based firm NVIDIA; by contrast, we identified only three models built with Chinese-made chips.*[23]
>
> *Huawei's PanGu-α, released in 2021, was one of the three exceptions. Trained using Huawei's in-house Ascend processors, the model appears to have been developed with significantly less computational power than best practices would recommend. Although it is currently perfectly legal for Chinese research groups to access cutting-edge U.S. chips by renting hardware from cloud providers such as Amazon or Microsoft, Beijing must be worried that the intensifying rhetoric and restrictions around semiconductors will hobble its AI companies and researchers.*[24]

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[23] Jeffrey Ding and Jenny Xiao. "Recent Trends in China's Large Language Model Landscape." *Centre for the Governance of AI*. April 2023.
[24] "Chinese AI Groups use cloud services to evade US chip export controls." *Financial Times*. March 8, 2023.

It is worth noting that the innovation-diffusion distinction is also relevant for discussions about the national security implications of LLMs. Almost all the attention has gone toward which country can develop the next breakthrough in foundation models; much less attention goes toward what happens after large models are trained and their adoption rate across different types of industries. From my preliminary research in this area, it seems that China still faces a large "implementation gap" in terms of making LLMs cost-effective to be used by small and medium-sized businesses.[25] General-purpose technologies like AI take time to diffuse, and if AI does truly transform the global economy, we are still in the early stages.

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 AI capabilities. My research suggests that the U.S.'s lead in AI capabilities over China should endure. The status quo, sometimes, functions as a defensible policy option. More specifically, claims that U.S. regulatory action on AI will allow China to race ahead in this domain do not hold water, and they should not confound deliberations over sensible guardrails on rapidly-advancing AI systems.[26]

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 AI and other emerging technologies. 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.[27]

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.[28] The U.S. should also invest in "technology diffusion institutions," including applied technology centers and dedicated field services, that encourage the adoption of AI techniques by small businesses.[29] All too often, it seems, the U.S. government's go-to

[25] Jeffrey Ding. 2022. "ChinAI #199: China's Hugging Face?" https://chinai.substack.com/p/chinai-199-chinas-hugging-face; Jeffrey Ding. 2023. "ChinAI #236: The LLM Implementation Gap" https://chinai.substack.com/p/chinai-236-the-llm-implementation.

[26] Helen Toner, Jenny Xiao, and Jeffrey Ding. 2023. The Illusion of China's AI Prowess. *Foreign Affairs*. https://www.foreignaffairs.com/china/illusion-chinas-ai-prowess-regulation.

[27] 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.

[28] 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.

[29] Shapira, Philip, and Jan Youtie. "The next Production Revolution and Institutions for Technology Diffusion." *The Next Production Revolution: Implications for Governments and Business*, 2017.

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.