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Testimony of Edward Parker[1]
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Co-chair Helberg and co-chair Wessel, the governments of both the United States and the People's Republic of China (PRC) consider quantum science and technology to be strategically important for ensuring their respective countries' economic and military leadership. In the United States, quantum science has been a priority area for federal research and development (R&D) for both the previous and current administrations, and the passage of the bipartisan National Quantum Initiative Act (Pub. L. 115-368) in 2018 significantly increased U.S. government funding and coordination in this area.[3] National Security Advisor Jake Sullivan has identified quantum technology as one of a few technologies that he believes "will be of particular importance over the coming decade."[4] In China, President Xi Jinping held a group study session of the Chinese Communist Party Politburo dedicated to quantum science, in which he stated that "developing quantum science and technology is of great scientific and strategic significance."[5] The PRC is also investing huge resources into quantum science R&D.

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[3] Public Law 115-368, National Quantum Initiative Act, December 21, 2018.

[4] The White House, "Remarks by National Security Advisor Jake Sullivan at the Special Competitive Studies Project Global Emerging Technologies Summit," September 16, 2022.

[5] Zhang Zhihao, "Xi Highlights Crucial Role of Quantum Tech," China Daily, October 19, 2020.

I would like to begin with the caveat that there is very high international collaboration in quantum science research.[6] For example, most quantum science research produced by U.S. scientists is coauthored with foreign collaborators. In fact, the United States and China are each other's largest scientific collaborators.[7] Therefore, discussing nations' quantum industrial bases in isolation does not capture the complete picture.

That having been said, by most relevant metrics, the United States and China are clearly the two leading nations in quantum science and technology. They each produce far more public scientific research and patenting in this area than any other nation.[8] They probably invest far more government funding into quantum R&D as well, although China has produced widely conflicting public numbers for its investment levels, so reliable numbers are hard to come by.[9] The United States and China have also publicly demonstrated the world's most-impressive specific technical achievements.

Comparison of Scientific Achievements and Priorities

The U.S. government has produced a public national strategy for quantum science,[10] as well as more detailed reports on specific subareas.[11] To my knowledge, the PRC government has not, and its overall priorities, plans, and timelines for integrating quantum technology into operational military systems are much less clear than those of the U.S. government. Nevertheless, we can draw some tentative conclusions from Chinese public scientific activity.

Quantum science is a dual-use technology; it has both military and civilian-commercial applications.[12] It is often divided into three subfields that each have potential military applications:

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[6] Edward Parker, Richard Silberglitt, Daniel Gonzales, Natalia Henriquez Sanchez, Justin Lee, Lindsay Rand, Jon Schmid, Peter Dortmans, and Christopher A. Eusebi, *An Assessment of U.S.-Allied Nations' Industrial Bases in Quantum Technology*, RAND Corporation, RR-A2055-1, 2023, https://www.rand.org/pubs/research_reports/RRA2055-1.html.

[7] Edward Parker, Daniel Gonzales, Ajay K. Kochhar, Sydney Litterer, Kathryn O'Connor, Jon Schmid, Keller Scholl, Richard Silberglitt, Joan Chang, Christopher A. Eusebi, and Scott W. Harold, *An Assessment of the U.S. and Chinese Industrial Bases in Quantum Technology*, RAND Corporation, RR-A869-1, 2022, https://www.rand.org/pubs/research_reports/RRA869-1.html.

[8] Parker et al., 2023.

[9] Parker et al., 2022.

[10] Subcommittee on Quantum Information Science, Committee on Science, National Science and Technology Council, "National Strategic Overview for Quantum Information Science," September 2018.

[11] Subcommittee on Quantum Information Science, Committee on Science, National Science and Technology Council, "A Coordinated Approach to Quantum Networking Research," January 2021; Subcommittee on Quantum Information Science, Committee on Science, National Science and Technology Council, *Bringing Quantum Sensors to Fruition*, March 2022.

[12] Edward Parker, *Commercial and Military Applications and Timelines for Quantum Technology*, RAND Corporation, RR-A1482-4, 2021, https://www.rand.org/pubs/research_reports/RRA1482-4.html.

1. *Quantum sensing* could improve positioning, navigation, and timing (PNT) capabilities and robust communications in challenging (e.g., GPS-denied) environments, as well as long-distance sensing capabilities.
2. *Quantum computing* could improve military logistics, modeling and simulation, scientific research, and codebreaking capabilities.
3. *Quantum communications* could improve the security of communications against enemy interception.

My high-level summary assessment of the Chinese quantum innovation ecosystem is that Chinese researchers are impressively fast followers across many quantum technology areas, but are rarely at the true forefront of innovation. The one exception is quantum communications, in which Chinese researchers are the world leaders.[13] But even in that subfield, they have significantly different R&D priorities from the United States, and so the two nations are not necessarily in direct technical competition over the same applications. A more detailed discussion follows.

Quantum Sensing

Chinese scientists publish slightly less high-impact research in quantum sensing than U.S. scientists do, and the foremost Chinese quantum scientist has admitted that "there is a gap" between the United States and China in this area.[14] Much of China's open research in quantum sensing focuses on remote imaging technologies, such as *quantum radar*.[15] However, the U.S. military has publicly identified quantum radar as impractical, suggesting a possible difference in prioritization between the two nations.[16]

Quantum Computing

There are many different technical approaches to quantum computing being pursued in parallel. The United States is in the lead in almost all of them, but there is one leading approach (using what are known as *superconducting-transmon qubits*) in which the Chinese are close behind.[17] Therefore, the size of the United States' lead is debatable.

Quantum Communications

China is the world leader in quantum communications, as measured both by highly cited scientific publishing and by deployed systems.[18] China's quantum communications R&D focuses on an application known as *quantum key distribution* (QKD), which might improve communications security against enemy interception. Chinese scientists have built the world's

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[13] Parker et al., 2022.

[14] Parker et al., 2022.

[15] Parker et al., 2023.

[16] Parker et al., 2023.

[17] Parker et al., 2022.

[18] Parker et al., 2022.

largest QKD network, known as the Jing-Hu Trunk Line, stretching 2,000 kilometers from Beijing to Shanghai.[19] They have also launched the only two known satellites capable of performing QKD from space,[20] which they have recently used to establish a secure communication link with Russia.[21] However, the U.S. National Security Agency has publicly assessed that QKD is not suitable for securing U.S. national security systems,[22] suggesting another difference in prioritization between the two nations.

Technology Transition and Military Operational Fielding

Broadly speaking, the field of quantum technology is still very nascent. The only quantum technology that is publicly known to be already deployed by any nation's military is atomic clocks, which underlie the Global Positioning System (among many other applications). The general expert consensus is that quantum sensing is the technology that is closest to useful deployment; in 2019, the Defense Science Board estimated that operational utility may arrive around the 2024–2029 time frame.[23] By contrast, the highest-impact applications of quantum computing, such as decryption, are unlikely to arrive before 2030.[24] It is therefore inherently challenging to discuss which country is currently "ahead," since one could defensibly argue that all players are still "tied at zero."

As I mentioned, there is very little public information about the PRC's plans for the operational military deployment of quantum technology. There is no public information on whether the People's Liberation Army (PLA) is using the national Chinese QKD network. One of the very few specifically *military* applications of quantum technology that the PRC is publicly pursuing is quantum radar[25]—but, as I mentioned above, the U.S. Department of Defense (DoD) considers that application to be fundamentally scientifically impractical.

The U.S. military has recently begun publicly testing quantum sensors in operational environments: U.S. and allied navies tested quantum gravimeters and inertial navigation systems

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19 Yu-Ao Chen, Qiang Zhang, Teng-Yun Chen, Wen-Qi Cai, Sheng-Kai Liao, Jun Zhang, Kai Chen, Juan Yin, Ji-Gang Ren, Zhu Chen, et al., "An Integrated Space-to-Ground Quantum Communication Network over 4,600 Kilometres," *Nature*, Vol. 589, January 14, 2021.

20 Stephen Chen, "China Launches New Satellite in 'Important Step' Towards Global Quantum Communications Network," *South China Morning Post*, July 27, 2022.

21 Victoria Bela, "China and Russia Test 'Hack-Proof' Quantum Communication Link for Brics Countries," *South China Morning Post*, December 30, 2023.

22 National Security Agency/Central Security Service, "Quantum Key Distribution (QKD) and Quantum Cryptography (QC)," undated.

23 Department of Defense Defense Science Board, "Applications of Quantum Technologies: Executive Summary," Office of the Under Secretary of Defense for Research and Engineering, October 2019.

24 National Academies of Sciences, Engineering, and Medicine, *Quantum Computing: Progress and Prospects*, The National Academies Press, 2019.

25 Liu Zhen, "China's Latest Quantum Radar Won't Just Track Stealth Bombers, but Ballistic Missiles in Space Too," *South China Morning Post*, June 15, 2018.

during the 2022 Rim of the Pacific (RIMPAC) naval exercises.[26] I am not aware of the PLA having conducted any comparable public operational tests of any quantum technology. Nor am I aware of any public Chinese research demonstrations of cutting-edge quantum sensors for PNT.

As I discussed, U.S. and Chinese researchers are focusing their research on different applications of quantum technology. This makes it challenging to assess which country is closer to military deployment, as they appear be to pursuing somewhat different R&D strategies—especially within quantum sensing and communications. My own assessment largely agrees with the U.S. DoD's position that QKD and quantum radar are unlikely to deliver significant military operational advantage. So, in my assessment, the United States is ahead of China—although not always very far ahead—in all quantum technologies that are likely to deliver an operational military advantage. However, the PRC government may have a different assessment.

Structure of China's Quantum Industrial Base

Like the United States, China has more than 100 universities and national laboratories that publish significant amounts of public research across all areas of quantum science.[27] China's military-affiliated universities are not at the forefront of Chinese public research in quantum science. The National University of Defense Technology is one of China's top 20 publishers of research in this field. But neither the PLA Academy of Military Sciences, nor the PLA National Defense University, nor the PLA Strategic Support Force's Aerospace Engineering University or Information Engineering University, nor any of the "Seven Sons of National Defense" universities are.[28] While many Chinese universities are active in quantum science, the single most important research institution is the Hefei National Laboratory for Physical Sciences at the Microscale in the city of Hefei in Anhui Province, which is affiliated with the University of Science and Technology of China.[29] This facility has a budget reported to be in the billions of dollars and has been the source of most of China's major public breakthroughs in the field.[30]

In the United States, private industry is at the forefront of most quantum technology deployment, but private industry appears to be a much less important component of China's industrial base. RAND research has identified a relatively small number of Chinese private companies that perform significant public R&D in quantum technology, and their total announced capital funding is a tiny fraction of the U.S. total. That having been said, there are a few notable Chinese companies, such as QuantumCTek and Origin Quantum Computing.[31] Most of these companies are located in Hefei, suggesting strong research collaboration with the

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[26] Subcommittee on Quantum Information Science, Committee on Science, National Science and Technology Council, *National Quantum Initiative Supplement to the President's FY 2024 Budget*, December 2023.

[27] Parker et al., 2022.

[28] This assertion is based on English-language publications only, using the affiliations provided by the articles' authors.

[29] Parker et al., 2022.

[30] Stephen Chen, "China Building World's Biggest Quantum Research Facility," *South China Morning Post*, September 11, 2017.

[31] "China's 3rd-Gen Superconducting Quantum Computer Goes into Operation," Xinhua, January 6, 2024.

national laboratory there.[32] Overall, the PRC's research efforts in quantum technology are more centralized—both institutionally and geographically—than the United States' are.

Large Chinese technology companies, such as Alibaba, Baidu, Huawei, Tencent, and ZTE, have also invested in quantum technology R&D, but they appear to have recently pulled back from that field. For example, Alibaba and Baidu have both shut down their quantum computing research laboratories since November 2023.[33]

To my knowledge, none of these research entities have publicly announced that they have provided any operational quantum technology to the PLA.

Connections to Organizations Outside China

The global quantum science R&D ecosystem is highly interconnected. Like every other leading nation's scientists, Chinese scientists collaborate extensively with foreign researchers. I am not aware of any formal, institution-level partnerships for quantum science research between Chinese and foreign research institutions; most scientific collaboration occurs organically between individual researchers.

Applied quantum science is a relatively nascent technology, so much of the technical progress is published openly, and all nations study one another's progress. One of the biggest Chinese breakthroughs to date—a cutting-edge quantum computer announced in 2021—used a very similar design as a quantum computer that Google had developed and publicly described two years earlier.[34] To be clear, there is no public evidence that the Chinese researchers obtained any technical information from Google (or from any other foreign organization) through any illegal or inappropriate means.

The supply chain for quantum technology is particularly important, but there is very little public information about the Chinese supply chain. Several key hardware components, such as dilution refrigerators and high-quality lasers at relevant frequencies, are mostly or entirely manufactured by European or Japanese companies, some of which are quite small.[35] The United States does not have a self-sufficient supply chain, and I suspect that China does not either. Cutting-edge "traditional" semiconductor microprocessors—such as those fabricated in Taiwan—do not appear to be critical to the quantum supply chain, since quantum systems have very different performance requirements from standard electronics.

A final important source of international connections is financial investment. There is significant international financial investment in quantum technology firms between U.S. and allied nations,[36] but I do not know of any financial investment in quantum technology between

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32 Parker et al., 2022.

33 "Baidu to Donate Quantum Computing Lab, Equipment to Beijing Institute," Reuters, January 3, 2024; Casey Hall, "Alibaba's Research Arm Shuts Quantum Computing Lab amid Restructuring," Reuters, November 27, 2023.

34 Qingling Zhu, Sirui Cao, Fusheng Chen, Ming-Cheng Chen, Xiawei Chen, Tung-Hsun Chung, Hui Deng, Yajie Du, Daojin Fan, Ming Gong, et al., "Quantum Computational Advantage via 60-Qubit 24-Cycle Random Circuit Sampling," *Science Bulletin*, Vol. 67, No. 3, February 15, 2022.

35 Parker et al., 2022.

36 Parker et al., 2023.

the United States and China (in either direction). The closest connection that I am aware of is that Sequoia Capital China—which at the time was owned by the U.S. finance company Sequoia Capital but was based in China—previously invested in an Australian quantum technology company.[37] However, Sequoia Capital later instituted a screening policy for investments in quantum technology companies and then spun off its China branch entirely.[38] So that link appears to have been cut.

Last year, the Biden administration issued an executive order restricting U.S. outbound financial investment in Chinese quantum technology firms. Given the lack of known financial connections between U.S. investors and Chinese technology firms, as well as the generally small role that private firms play in the Chinese quantum industrial base, I believe that this executive order will have very little impact on China's R&D efforts over the short or medium term. Over the long term, the order may dissuade U.S. investors from *beginning* investment in the Chinese quantum commercial sector, if that commercial sector grows to become a larger part of the Chinese quantum industrial base. But because there is currently very little connection between the U.S. financial system and the Chinese quantum ecosystem, I do not think that any U.S. government actions regarding outbound financial investment would have a significant impact on Chinese quantum R&D efforts.

Recommendations

I believe that the United States has the good fortune to be at the forefront of almost all of the most important subfields of quantum technology. Moreover, it has a huge advantage that the PRC does not: a network of close alliances with many of the other leading nations in this field. For example, the United States has signed bilateral joint statements of cooperation in quantum science R&D with nine different allied nations.[39] Also, the most important applications of quantum technology are still probably at least five to ten years away, so I believe it is essential to take a long-term view toward maintaining the United States' advantages.

There are still significant scientific advances that need to be made before the full promise of quantum technology can be unlocked. If Congress determines that this technology should be a strategic priority, then the most important step toward that goal would be to continue to invest in scientific research in the field.[40] Another important step would be to strengthen the U.S. skilled workforce in this field—including both the domestic and the foreign pipelines of skilled talent—while ensuring that appropriate protections against intellectual property loss are in place.[41]

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[37] Parker et al., 2023.

[38] Parker et al., 2023.

[39] Edward Parker, *Promoting Strong International Collaboration in Quantum Technology Research and Development*, RAND Corporation, PE-A1874-1, 2023, https://www.rand.org/pubs/perspectives/PEA1874-1.html.

[40] Parker et al., 2023.

[41] Subcommittee on Economic and Security Implications of Quantum Science, Committee on Homeland and National Security, National Science and Technology Council, *The Role of International Talent in Quantum Information Science*, October 2021; Subcommittee on Quantum Information Science, Committee on Science,

The financial stability of the U.S. commercial quantum industry is not guaranteed; no U.S. quantum technology company has yet reported any significant revenue or clear commercial application. Broad export controls on quantum technology would run the risk of slowing scientific progress and stifling a nascent commercial industry.[42] I believe that *narrowly targeted* export controls on specific Chinese (or other) organizations of concern are low-risk. But I believe that Congress should carefully consider the impacts on the U.S. commercial industry of any proposed broad export controls on quantum technology, unless those export controls are directly tied to a concrete military capability.

There are three other important aspects of the emerging quantum technology ecosystem that the U.S. government should consider understanding and monitoring:

1. the financial health of small, specialized quantum technology companies
2. the flows of skilled talent and intellectual property between the United States and competitor nations (including through intermediate allied nations)
3. the supply chain for critical components and materials.

I do not see any clear needs for immediate action regarding these topics, but all three of them represent potential risks to the long-term stability of the emerging quantum ecosystem.

National Science and Technology Council, *Quantum Information Science and Technology Workforce Development National Strategic Plan*, February 2022.

[42] Parker et al., 2022.