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How Innovative Is China in Quantum?

HODAN OMAAR AND MARTIN MAKARYAN | SEPTEMBER 2024

China's lead in quantum communications is undeniable, but its overall quantum prowess is limited; without computing breakthroughs, the United States still holds the upper hand.

KEY TAKEAWAYS

- China leads in quantum communications, lags behind in computing (where the United States excels), and matches the United States in sensing, excelling in market-ready tech, while the United States dominates high-impact areas.
- China claims over $15 billion in public quantum funding, far outpacing the United States. While U.S. private funding is higher, China offsets its private sector shortfall with massive public investment.
- China's quantum strategy is insular, relying on domestic resources with limited global collaboration. This approach yields rapid gains but poses long-term risks in sustaining complex technology advancements.
- Government-led industrial hubs such as Hefei's "Quantum Avenue" are pivotal for cultivating China's quantum industry, creating a direct pipeline from academic research to strategic, market-ready technologies that serve national priorities.
- China's state control over quantum research and development (R&D) is growing, with firms such as Alibaba and Baidu exiting quantum research, aligning innovation with national goals and reducing private sector involvement.
- China strategically benefits from open innovation environments abroad, selectively engaging with them while protecting its own quantum advances, creating an asymmetric knowledge-sharing environment.
- The United States should rapidly scale funding, foster industry-led innovation, and streamline the path from research to market to ensure its quantum leadership translates into real-world economic and strategic gains.

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INTRODUCTION

China is actively pursuing advancements in quantum information science (QIS), which harnesses the principles of quantum mechanics to process and transmit information in fundamentally new ways, and some of these advancements outstrip the United States in scale and scope, making U.S. leadership in quantum far from assured. Quantum technologies not only are important for national security, but they also have the potential to exert a transformative influence on the economy and society. Being at the forefront of this technological frontier is strategically crucial for the United States in terms of both its economic and societal well-being.

Overall, China dominates in quantum communications, lags behind in quantum computing, and roughly matches the United States in quantum sensing. State-funded labs, elite universities such as University of Science and Technology of China (USTC), and a select group of private companies are advancing technologies that align closely with national priorities. In quantum communications, China has secured global leadership, notably demonstrated through the development of the world's longest quantum key distribution (QKD) network—the 1,200-mile Beijing-Shanghai backbone. Coupled with the groundbreaking Micius satellite, which extends quantum communication over even greater distances, this network has put China at the forefront of secure, long-distance quantum communication. However, in quantum computing, China lags behind significantly, particularly in hardware and the practical implementation of quantum systems. In quantum sensing, China leads in certain aspects and the United States in others. This contrast—China's leadership in the more market-ready quantum sensing versus its lag in the less-mature quantum computing—illustrates its strength in swiftly refining and applying existing research, as well as its limitations in foundational innovation.

China is fully aware of its strengths and plays to them. At the core of its quantum innovation strategy is a relentless focus on translating cutting-edge research into practical, commercial applications. Government initiatives have created specialized hubs such as Hefei's Quantum Avenue, where academic research is seamlessly converted into market-ready technologies. China's approach is notably insular, with limited international collaboration in research publications. While this strategy has yielded rapid gains, especially in quantum communications, it also presents long-term risks. The immense cost and complexity of quantum technology development, as well as its globally dispersed supply chain, requires international cooperation—something that China's inward-looking approach may struggle to sustain. China benefits significantly from the open innovation environments of other nations, yet it is notably protective of its own advances. While it leverages global research, China restricts the sharing of its developments, reflecting a strategic approach to maintaining a competitive edge.

The United States should take immediate and decisive action to ensure its leadership in quantum technology. This includes significantly increasing funding for R&D, particularly through the reauthorization of the National Quantum Initiative (NQI). Congress should support industry-led innovations that address critical public sector challenges, accelerating the commercialization of quantum technologies. Additionally, the United States should avoid imposing rigid quantum standards prematurely, allowing the industry to innovate and evolve naturally. Careful, targeted export controls are necessary to protect U.S. advancements while maintaining the flow of ideas and talent essential for progress. By balancing strategic investment, innovation, and security, the United States can ensure it remains at the forefront of global quantum technology.

BACKGROUND AND METHODOLOGY

The Smith Richardson Foundation provided support to the Information Technology and Innovation Foundation (ITIF) to assess how innovative Chinese industries are. As part of this research, ITIF is focusing on industries and technologies, including quantum technologies. Quantum technologies scoped in this report are the following:

- **Quantum communications,** which refers to the development of secure communication protocols that use the principles of quantum mechanics to ensure the confidentiality and integrity of transmitted information.
- **Quantum computing,** which refers to the development of computers that use quantum mechanics to perform calculations exponentially faster than classical computers.
- **Quantum sensing,** which refers to the use of quantum mechanics to enhance sensors and measurement science.

To be sure, it's difficult to assess the innovation capabilities of any country's industries, but it is especially difficult for Chinese industries. In part, this is because, under President Xi Jinping, China discloses much less information to the world than it used to, especially about its industrial and technological capabilities. Notwithstanding this, ITIF relied on three methods to assess Chinese innovation in quantum. First, we conducted interviews and held a focus group roundtable with global experts on the Chinese quantum industry, and supplemented that with a thorough review of literature on Chinese innovation in this space. Second, we assessed global data on quantum innovation, including scientific articles and patents. Finally, we conducted an in-depth case study evaluation of two quantum companies identified as leading Chinese companies by our panel of experts.

OVERVIEW OF CHINA'S QUANTUM INDUSTRY

Despite large numbers of reported Chinese quantum companies, there are only around 14 private-sector firms that can be identified as making significant contributions to quantum technology, including nine start-ups and five major tech companies (see table 1).[1] Leading the way are prominent start-ups such as Origin Quantum and QuantumCTek alongside giants such as Alibaba, Baidu, and Tencent. These five companies command the largest share of China's quantum market.[2]

Table 1: Firms innovating in China's private-sector quantum ecosystem

	Quantum-Focused Start-Ups	Large Technology Companies With Quantum Research Groups
1	Ciqtek	Alibaba Quantum Computing Lab
2	Kunfeng	Baidu Quantum Computing Lab
3	Origin Quantum	Huawei HiQ
4	Qasky	Tencent
5	QuantumCtek	ZTE

	Quantum-Focused Start-Ups	Large Technology Companies With Quantum Research Groups
6	QuDoor	
7	Shenzhou Quantum Communication Technology	
8	SpinQ	
9	TuringQ	

A recent exit of large Chinese tech companies from quantum research signals a broader push by the state to tighten control over quantum R&D in China.

Private sector investment in quantum technology in China pales in comparison to that in the United States. Chinese start-ups are severely underfunded, with the RAND 2022 report identifying only $44 million in capital, a stark contrast to the $1.28 billion available to U.S. start-ups.[3] A 2023 McKinsey report finds similarly yawning private investment gaps, noting total private investment in quantum start-ups in the United States was roughly 10 times larger than in China.[4] U.S. private investors don't just outstrip China though—they lead the world in quantum technology investments, including surpassing EU private investment by more than fivefold.[5] This dominance stems not only from the scale of available capital but also from an investor culture deeply committed to taking calculated risks that propel innovation forward. The severe funding gap in China makes it hard for its start-ups to invest heavily in conducting substantial research, a sharp contrast to their better-funded U.S. counterparts, but China is turning this weakness into a strength by focusing its start-ups on the commercialization of existing quantum technologies and making up for the gap in public funds (covered in the section later on government policies).

A recent exit of large Chinese tech companies from quantum research signals a broader push by the state to tighten control over quantum R&D in China. Both Alibaba and Baidu have shut down their quantum research divisions, transferring their assets to state-linked institutions. For example, Baidu handed over its quantum research facilities to the Beijing Academy of Quantum Information Sciences, while Alibaba transferred its quantum lab to Zhejiang University. [6] While some analysts attribute these exits to economic pressures—such as the high costs and uncertain returns of quantum research—a more compelling explanation is that the government is consolidating control to ensure that quantum R&D aligns better with national strategic objectives.[7] By centralizing quantum research within state-affiliated institutions, the government is not only diminishing the role of private companies but also directing the course of innovation.

ASSESSING CHINESE QUANTUM INNOVATION

To evaluate China's advancements in quantum technologies, our focus is on understanding both the "what" and the "how": what quantum innovations China is excelling in and how these developments are being achieved. While metrics such as qubit count, coherence times, and gate fidelity often dominate discussions about quantum capabilities, they are insufficient and unreliable measures of progress when it comes to China given the opacity surrounding Chinese data and methodologies.

Which Quantum Technologies Does China Innovate In?

China has a significant lead in quantum communications, while the United States has a significant lead in quantum computing.[8] One expert noted that this difference underscores two distinct national strategies for navigating the quantum technology landscape: While the U.S. invests in the long-term potential of quantum computing—a less mature but highly promising technology with broad applicability across multiple industries—China focuses on the immediate and secure applications of quantum communications, a more mature set of technologies with a narrower market scope.

After the 2013 Snowden leaks, President Xi Jinping, concerned about potential vulnerabilities in China's communications, prioritized quantum communications and security in the 13th Five-Year Plan.[9] Since then, China has been moving swiftly, solidifying its lead in the global race for secure communications, particularly in QKD, which is perhaps the most advanced subfield of secure communications, leveraging the principles of quantum mechanics to create a virtually unbreakable method of encrypting data. There are ground-based systems that use both fiber-optic cables to securely transmit data across cities or between close regions and satellite-based systems that can connect secure communications across much longer distances, even globally. China has the most ambitious demonstrations of this technology, namely through what is called the Beijing-Shanghai backbone, which is the longest QKD network in the world and stretches over 1,200 miles using fiber-optic cables.[10] To extend the secure communication even further, China has integrated satellite links into this network. These satellite links allow data to be securely transmitted between locations that are too far apart to be connected directly by fiber optics, such as between different continents, maintaining secure quantum communication far beyond what is possible with ground-based systems alone.

China's QKD ambitions took a step forward with the launch of the Micius satellite in 2016, a project that pushed beyond the impressive achievements of the Beijing-Shanghai backbone. Led by Pan Jianwei and his team at USTC, in collaboration with the Chinese Academy of Sciences, Micius became the world's first quantum science satellite.[11] It pioneered secure quantum communication over thousands of miles, successfully transmitting quantum keys between Asia and Europe, a feat that involved collaboration with research teams in Austria. By enabling quantum key exchange across continents, Micius demonstrated the potential to build a global quantum internet—a network that would use quantum technology to transmit information in a way that is far more secure than today's Internet, protecting data from being intercepted or tampered with. Micius proved that quantum communication could span the globe, moving beyond local networks to create a secure, interconnected world—far surpassing the Beijing-Shanghai backbone and marking China as a leader in the future of global secure communications.

Figure 1: A 1,200-mile quantum communications corridor connects quantum networks in four Chinese cities[12]

Other countries recognize the importance of staying competitive in QKD and have made investments to stay at the forefront, but the United States has lagged behind. The European Union has launched the EuroQCI project, a major initiative launched to develop a secure quantum communication network across Europe, and South Korea is developing a nationwide QKD backbone of its own, but no such investments are seen in the United States. A 2024 report from the U.S. Quantum Economic Development Consortium (QED-C) reads, "Currently, the U.S. government is not investing in such testbeds or demonstrations, ensuring it will be a follower and not a leader in the development of technical advances in the field."[13]

Where China lags behind however, is in quantum computing. China's lag is significant across multiple areas, including in hardware development and algorithm sophistication.

First, in hardware development, the United States has taken a commanding lead over China. To build a functional quantum computer, one must create a physical system that encodes and then controls and manipulates qubits to carry out computations. There are currently two leading technologies to do so, and U.S. companies lead in the development of both. The first approach uses atomic ions, such as beryllium ions, trapped in a vacuum to represent qubits.[14] Unlike traditional circuits, wherein bits move through different components of the circuit, qubits (i.e., the ions) in this method are held in place and manipulated by electric fields. The efforts of U.S. companies such as IonQ, which was the first to make an ion-based quantum computer available through cloud platforms such as Amazon Braket, Microsoft Azure, and Google Cloud, as well as Honeywell Quantum Solutions, which has set records for performance and error rates in ion-based systems, exemplify U.S. leadership in this space. The second (and prime method) for building a quantum computer uses the unique properties of superconducting materials. When certain materials, such as the metal niobium, become very cold, they lose their electrical resistance and can transport electrons and conduct electricity. In particular, they not only act as superconductors, but also start to exhibit quantum mechanical effects. These metals can be used to create quantum transistors, much like silicon is used to build classical transistors. Experts we spoke to noted that U.S. companies such as IBM, Google, and Rigetti, and those of its allies such as Canadian-based D-Wave, have some of the most advanced quantum processors using superconducting qubits. They have achieved breakthroughs in qubit coherence times and error rates, key factors in scaling up superconducting quantum computers, while China's advancements in this area have been slower and less consistent, often lagging behind in the ability to produce high-quality, scalable qubits. However, China's recent achievements, such as the export of its first domestically developed superconducting quantum chip by SpinQ, indicate that it is making strides to close the gap.[15]

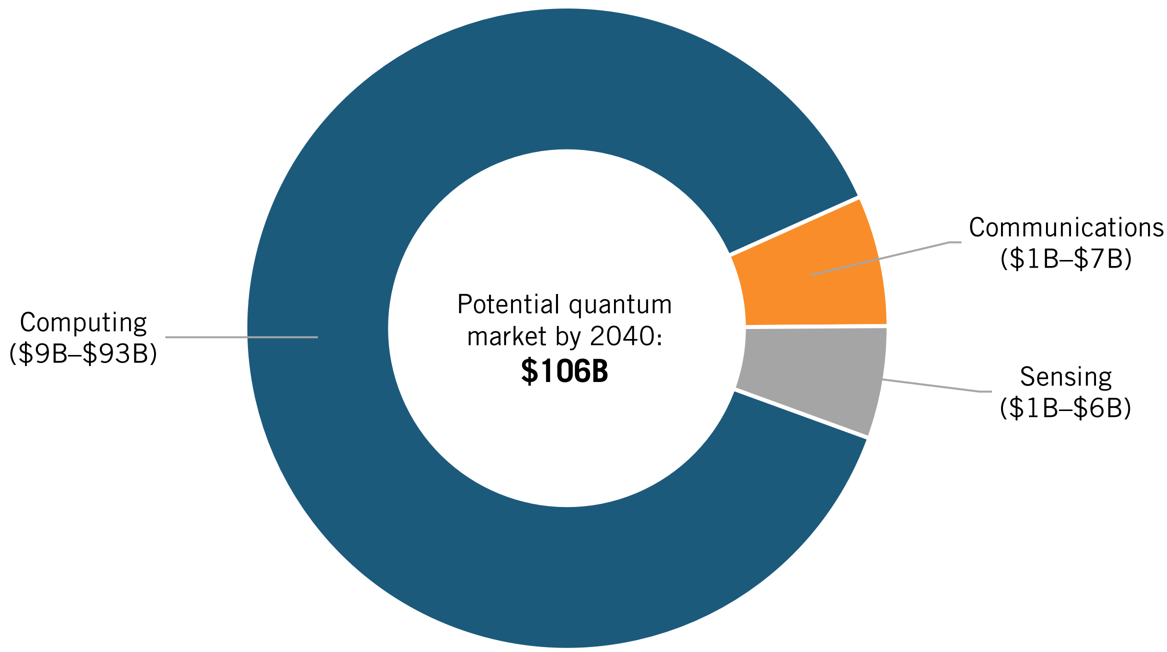
China's strategic focus on near-term quantum technologies enables it to lead in technologies that are closer to market readiness, but it may be overlooking the future potential of quantum computing.

Second, when it comes to algorithm development, or building blocks that run on top of the foundation of quantum computers, the United States again leads China. Two of the most famous quantum algorithms, Shor's algorithm for factoring large numbers and Grover's algorithm for deciphering encrypted messages more quickly, were developed by U.S. researchers. U.S. companies and companies from allied countries such as U.K.-based Quantinuum and Q-CTRL in Australia are leading the charge in applying quantum algorithms to real-world problems. One expert noted that China's efforts, while growing, have not yet matched the depth and breadth of the other countries' initiatives, leaving them behind in developing quantum software that can harness the full potential of quantum hardware.

In quantum sensing, leadership is closely contested according to participants and echoed in existing literature on quantum. Some highly cited research suggests that China has a marginal lead, while other recent research says that the United States enjoys a comfortable lead over China.[16] Innovation indicators on research output (see the section below) shows research in this technology is virtually neck and neck. Leadership in this field is crucial for near-term applications, as quantum sensing technologies are among the most advanced, with several already reaching high levels of maturity.[17] These technologies are already making inroads into various industrial applications, offering higher sensitivity and new capabilities that classical sensors can't match. In health care, they're enabling more precise cardiac monitoring and advanced brain-machine interfaces.[18] The Chinese military claims to be using these sensors for detecting submarines and other hidden threats.[19] And in materials science, this technology is improving the detection of defects at an unprecedented level of detail.[20]

Overall, China's strategic focus on near-term quantum technologies enables it to lead in technologies that are closer to market readiness. Some experts noted that by prioritizing these immediate gains, China may be overlooking the future potential that quantum computing holds—a technology that, despite its current developmental challenges, promises to revolutionize sectors from pharmaceuticals to finance. Indeed, the global quantum technology ecosystem shows a clear hierarchy in the market sizes of the three fields. Quantum computing dominates the landscape, estimated by McKinsey to capture approximately 87 percent of the total quantum technology market by 2040, while quantum communications is estimated to account for around 7 percent and quantum sensing 6 percent.[21]

Figure 2: Projected breakdown of the global quantum technology ecosystem by 2040, by market segment[22]



That said, betting on a small certainty today may be worth more than a big gamble tomorrow because the benefits of quantum communications are evident while the scale and payoff of quantum computing remain uncertain.

How Does China Innovate in Quantum Technologies?

From our roundtable discussion, several key themes emerged that help explain why, despite the small size of its industry, China's quantum ecosystem consistently punches above its weight.

First, participants noted that China's approach to quantum prioritizes transforming innovations into tangible products. They noted that, unlike the United States, which often focuses on knowledge creation, China ensures that innovations move seamlessly from the lab to the market. Indeed, the Chinese government plays a pivotal role in linking research institutions with industry. This connection is particularly evident in places such as Hefei, where the Hefei National High-tech Industry Development Zone acts as a conduit between academic research and commercial applications. Within this zone, government initiatives are focused on aligning scientific breakthroughs with industrial demands, fostering collaborations between universities, research labs, and private enterprises. This approach has proven especially effective in quantum technology, with Hefei emerging as a central hub for quantum enterprises.

A prime example of this successful integration is Quantum Avenue within the Hefei National High-tech Industry Development Zone, which has become a beacon of China's quantum technology industry. This specialized area on Yefei Road is said to host around 20 quantum technology companies, embodying the zone's role as a key incubator for quantum enterprises.[23] The concentration of these firms in one location accelerates the transition of quantum research from theory to application. Breakthrough innovations from this street have included superconducting quantum computing prototypes, millimeter wave chips, and the renowned Micius satellite. It is also home to at least four of the nine leading quantum start-ups: Ciqtek, Origin Quantum, Qasky, and QuantumCTek listed in table 1. According to one expert we spoke to, the key to China's success in developing an industrial quantum ecosystem in Hefei is its ties to a strong university—indeed, its strongest university in quantum, USTC—as a central anchor. This mirrors comments from quantum experts in China; Pan Jianwei, who is often referred to as China's "father of quantum" and is cofounder of QuantumCTek, has been reported to have said, "With the active participation of leading enterprises and guidance from the government, an industrial chain that covers the equipment, network, safety, and standards of quantum communication has been basically formed in China."[24]

Quantum Avenue within the Hefei National High-tech Industry Development Zone has become a beacon of China's quantum technology industry.

Second, the discussion highlighted the speed at which China is advancing in quantum technology. Participants pointed out that the United States currently approaches quantum innovation as a "Vannevar Bush science project" rather than as a national security or competitiveness priority. This refers to the linear model of innovation, often attributed to Vannevar Bush, a key figure in the development of U.S. science policy. In this model, basic research leads to applied research, which then leads to development and eventually to commercial products. It's a step-by-step process that can be slow and disjointed, with each stage often handled by different entities (e.g., universities for research, companies for development). In contrast, China's approach is designed for speed and efficiency. The country's strategy centralizes efforts and streamlines the transition from research to application. At the center of China's quantum research is USTC, now the country's leading hub for QIS.[25] This prominence largely stems from the Chinese Academy of Sciences (CAS) Key Laboratory of Quantum Information, which was brought to USTC through the efforts of Guo Guangcan, a renowned physicist and pivotal figure in QIS. Guo's leadership secured this prestigious government lab for the university, tightly integrating national research priorities with the university's academic strengths. Since around 2017, China has increasingly concentrated its quantum research efforts at USTC, particularly in high-impact areas. This centralization has solidified USTC's position as the driving force behind China's leadership in QIS.

Third, panelists highlighted China's centralized approach to funding quantum research. Indeed, the Chinese funding system for quantum is concentrated and relies heavily on the National Natural Science Foundation of China (NSFC). This organization is responsible for funding around 50 percent of quantum publications in China across quantum computing, quantum sensing, and quantum communications.[26] The panelists critiqued the comparative U.S. system for its "stovepiped" funding mechanisms. Funding sources in the United States are significantly more diverse, with even the government sources distributed across federal departments, which according to participants leads to inefficiencies and a lack of strategic coordination, ultimately slowing progress and making it harder for the United States to compete with China's more unified approach. Relatedly, the discussion highlighted China's readiness to fund high-risk quantum start-ups, even at the risk of failure, while the United States remains more cautious. As discussed in the previous section, China invests boldly in ambitious projects such as quantum communication networks prototypes, aiming for technological leadership. One expert noted this willingness to take risks positions China to achieve significant breakthroughs and potentially dominate quantum science, while the United States has taken a more conservative approach, focusing on more theoretical projects.

The Chinese funding system for quantum is concentrated and relies heavily on the National Natural Science Foundation of China.

Fourth, participants raised concerns that while science is a global good, China often benefits disproportionately due to its reluctance to share breakthroughs at the same rate it absorbs them. Indeed, although China eagerly taps into global innovations, it remains reluctant to share its own breakthroughs with the world. This inward-looking approach is particularly stark in quantum technology. While nearly half of U.S. research papers in quantum computing, communications, and sensing are coauthored with international partners, China's figures linger far behind, with just 29 percent, 19 percent, and 23 percent, respectively.[27] This pattern reveals a broader strategy: China focuses its research within its borders, relying heavily on domestic collaboration, especially among its universities, while the United States embraces a more globally integrated and open research ecosystem, drawing on the strengths of universities, research institutes, and private companies alike. While this strategy may raise alarms among policymakers, experts we consulted suggest that China could be setting itself up for long-term challenges. The immense cost, complexity, and scale required to innovate and manufacture quantum technologies, much like semiconductors, are simply too great for any single nation or enterprise to tackle alone. By limiting international collaboration, China risks hindering its own progress in a field where global cooperation is not just beneficial but essential.

Finally, one expert expressed frustration over a lack of centralized direction in academic research within the broader U.S. system, especially when contrasted with China's highly coordinated and government-directed approach to quantum research. In China, key research initiatives are steered by government labs, such as the National Laboratory for Quantum Information Sciences and the CA S Key Laboratory of Quantum Information—both in Hefei. These labs, along with the Beijing Academy of Quantum Information Sciences and the Shanghai Institute of Microsystem and Information Technology, operate under a unified national strategy, ensuring that research efforts align closely with state objectives. Leading universities, including USTC, Tsinghua University, and the Beijing University of Posts and Telecommunications, also contribute to this centralized framework, responding directly to government-set priorities and goals.

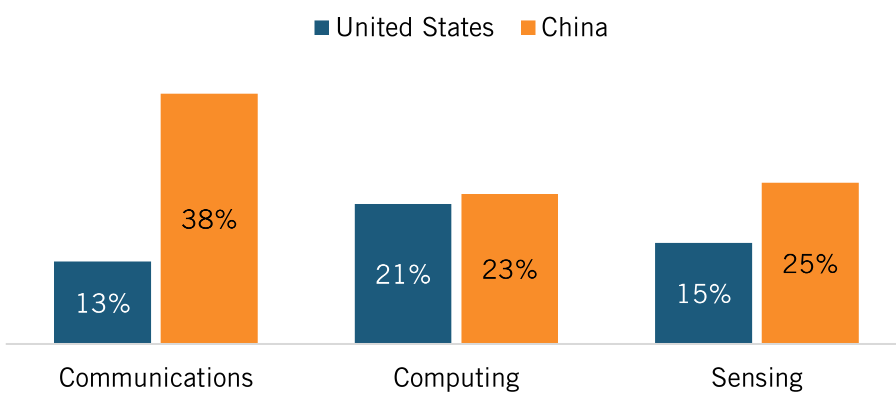
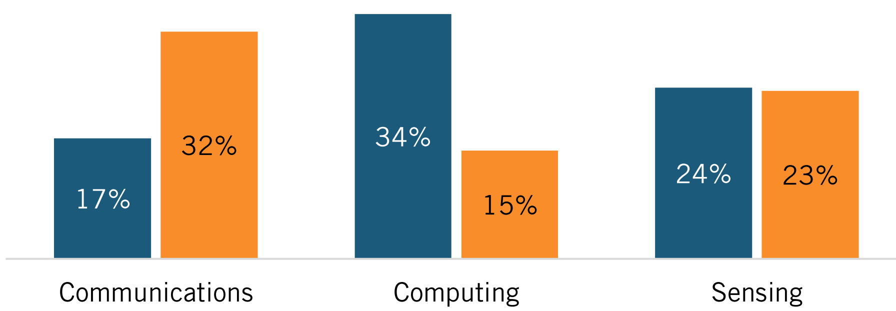
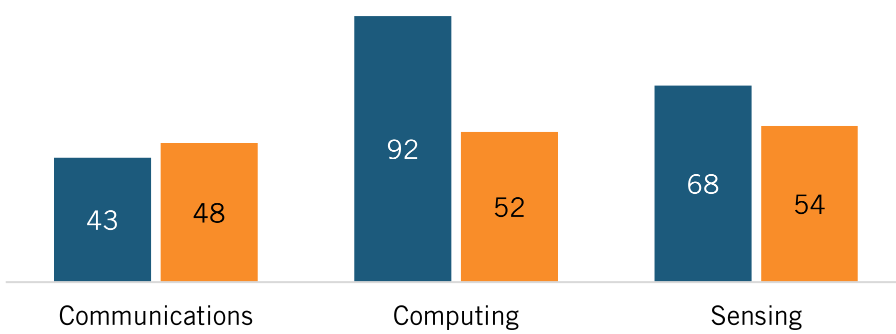
ANALYSIS OF INNOVATION INPUTS TO CHINA'S QUANTUM SECTOR

This section examines indicators assessing China's quantum competitiveness, considering scientific publications and patenting levels.

Scientific Publications

In quantum communications, China leads in both the quantity and quality of research, significantly outpacing the United States. In quantum computing, China produces more research but the United States far outperforms China in terms of research quality. In quantum sensing, China produces more research, but the two countries are neck and neck in terms of quality.

Table 2: Comparative research metrics in quantum technologies[28]

Metric	Quantum Technologies
Share of Global Research Output	
Share of Top 10% Most-Cited Research	
H-index	

In quantum communications, China leads globally, producing 38 percent of the world's publications compared with 12.5 percent by the United States. China also ranks first in research quality, with 31.5 percent of its publications in the top 10 percent and an H-index of 48 (a metric that measures both the productivity and citation impact of the publications), while the United States ranks second with 16.7 percent in the top 10 percent and an H-index of 43.

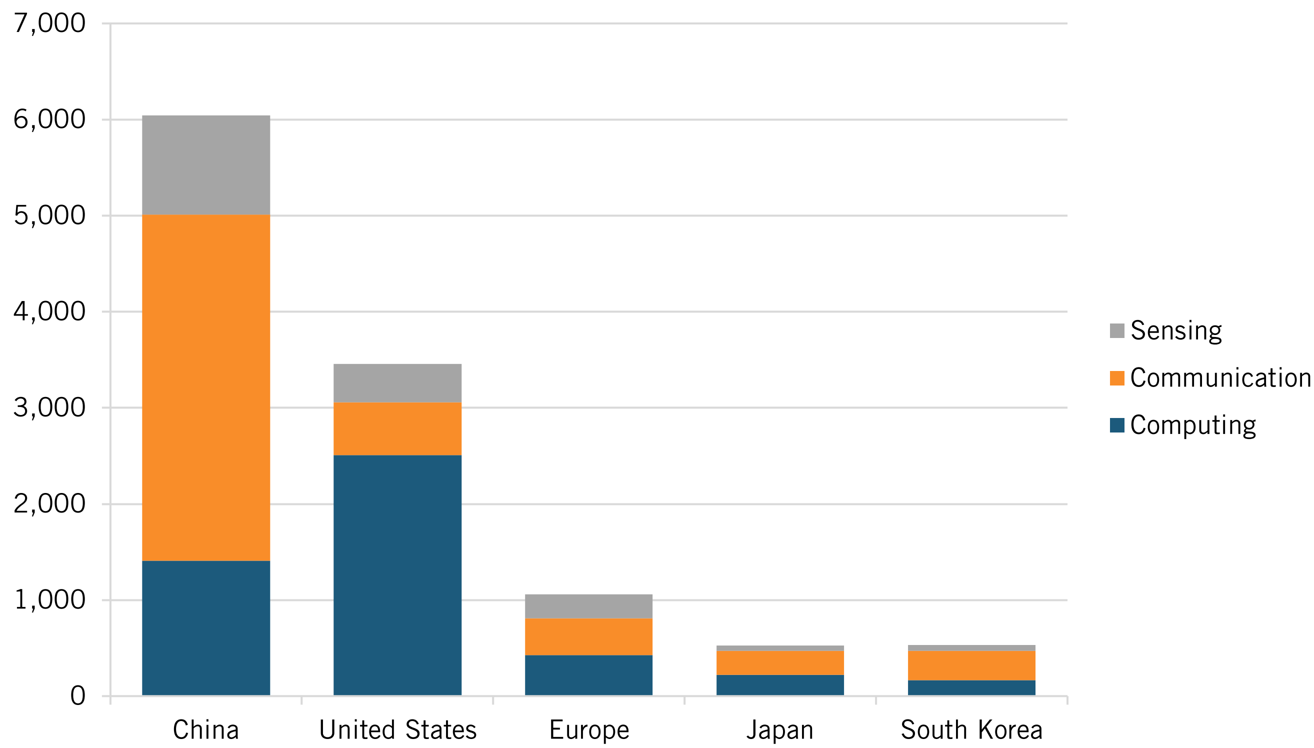
In quantum computing, China slightly outpaces the United States in research volume, contributing 22.8 percent of global papers versus the United States' 21.3 percent. However, the United States excels in research quality, with an H-index of 92 compared with China's 52, and 33.9 percent of United States publications in the top 10 percent, compared with 15 percent for China.

In quantum sensing, China produces more research, accounting for 24.5 percent of global papers, while the United States contributes 15.4 percent. Nevertheless, the United States leads in research quality with an H-index of 68 versus China's 54, and about the same higher top 10 percent publication representation, 23.7 percent compared with China's 23.3 percent.

Patents

China far and away leads in domestic quantum communication patents, and has a considerable lead in quantum sensing patents, while the United States leads in quantum computing patents (see figure 3). In Europe, there is no significant specific focus, and it has a balanced portfolio across all three technologies (whereas in the other regions, quantum sensing tends to lag behind).

Figure 3: Number of patent families per quantum technology[29]



In China, the main assignees for quantum communication and quantum sensing patents are a mix of public sector institutions and start-ups rather than large corporations. For instance, start-ups such as QuantumCTek and Ruban Quantum Technology lead in quantum communication patents while CAS's engineering research institute leads in quantum sensing.[30] In contrast, U.S. leadership in quantum computing patents is primarily driven by large companies, including IBM, Microsoft, Google and Intel.

Domestic patents in quantum technologies are particularly telling in China's case, as they underscore the nation's focus on national security over commercial objectives. Quantum technologies in China are seen as critical to national defense and infrastructure. By prioritizing domestic patents, China demonstrates its intent to maintain strict control over its technological advancements, ensuring they remain within its borders and are protected from external influence

However, to fully understand the global significance of these innovations, it's essential to look beyond domestic patents. While domestic patents indicate China's intent to protect and control its advancements internally, the patents that truly shape global markets and drive international competition are those that are extended beyond the country of origin. Therefore, table 3 focuses on international patent families—those filed in multiple countries—and provides the top assignees across quantum communications, computing, and sensing. This broader view reveals a different dynamic: While China's domestic focus is strong, its global footprint is less pronounced than that of other nations. Only two Chinese companies—Huawei and Alibaba—make it into the top 10 for quantum communications, with no Chinese representation in the top tiers of quantum computing or sensing. This contrast underscores China's focus on securing its innovations domestically, while global influence remains concentrated among foreign companies that prioritize broader international patent coverage.

Table 3: Top 10 patent assignees, considering only international patent families[31]

	Quantum Communications	Quantum Computing	Quantum Sensing
1	Toshiba (Japan)	IBM (USA)	Lockheed Martin (USA)
2	Huawei (China)	Microsoft (US)	Thales (France)
3	NEC (Japan)	Google (USA)	Honeywell (USA)
4	Alibaba (China)	Northrop Grumman (USA)	Harvard (USA)
5	Magiq Technologies (USA)	Intel (USA)	Northrop Grumman (USA)
6	ID Quantique (Switzerland)	Fujitsu (Japan)	Element Six (UK)
7	LG Electronics (S. Korea)	Toshiba (Japan)	CNRS (France)
8	ETRI (S. Korea)	NEC (Japan)	KRISS (S. Korea)
9	Nokia (Finland)	Hitachi (Japan)	Tokyo Tech Institute (Japan)
10	Arqit (UK)	Quantinuum (UK)	MIT (USA)

COMPANY CASE STUDIES

This section provides case study analyses of two Chinese quantum companies; they were selected based on discussions with our expert participants as two companies conducting meaningful innovation in the Chinese quantum ecosystem.

Origin Quantum

Origin Quantum, established in 2017 by quantum physicists Guo Guoping and Guo Guangcan from USTC, is at the forefront of China's efforts in quantum computing. Headquartered in Hefei, the company has quickly become a critical player in developing superconducting quantum computers. Origin Quantum has played a key role in positioning China as a contender in the global quantum race, although it acknowledges significant gaps in performance compared with Western leaders such as IBM and Google.

Origin Quantum's flagship achievement is the development of the Wukong quantum computer, China's first home-grown superconducting quantum computer. The Wukong, powered by a 72-qubit superconducting chip, has been accessible to users worldwide since January 2024, and has been accessed by users from 125 countries to complete over 250,000 quantum computing tasks.[32] This global accessibility underscores Origin Quantum's ambition to compete in the global quantum computing race, even as it faces stiff competition from more established Western companies.

A significant factor in Origin Quantum's approach is its commitment to full-stack quantum computing solutions, which include everything from the development of quantum chips to the creation of software platforms that make these systems operational. Unlike many quantum computing firms that focus primarily on either hardware or software, Origin Quantum integrates both, aiming to create a comprehensive quantum ecosystem. This approach sets them apart, especially in China, where the quantum computing industry is still maturing.

Origin Quantum builds on foundational research pioneered in the West but has adapted and enhanced these technologies to fit within China's strategic goals. The Wukong chip's development is seen as China's "entry ticket" into the field of superconducting quantum computer manufacturing. While the company leverages existing knowledge, it focuses on integrating these advancements into a domestic supply chain, allowing China to reduce its dependence on foreign technologies and pave the way for future innovations. Furthermore, the company has focused on tailoring its quantum technologies to align with China's national strategy. This includes optimizing its quantum computing systems for specific applications such as secure communications, quantum simulations, and other areas critical to national security and economic development.

Despite its achievements, Origin Quantum still faces significant challenges in matching the performance and industrial applications of Western leaders such as IBM and Google. While the Wukong quantum computer represents a major milestone, the company acknowledges that it lags behind in areas such as qubit scaling and practical deployment, where Western companies have made more substantial progress.

QuantumCTek

QuantumCTek is one of China's leading quantum technology companies, specializing in quantum communication products and services. Established in 2009, the company is headquartered in

Hefei and plays a crucial role in China's quantum communication infrastructure. As the first quantum technology company to go public in China, QuantumCTek has become a cornerstone of the country's ambition to lead in quantum innovation.

QuantumCTek was founded by a group of prominent scientists, including China's "father of quantum" Pan Jianwei and leading quantum pioneer Guo Guangcan, both closely affiliated with USTC.[33] The company was a direct spin-off from USTC's research, supported by the Chinese government as part of its broader national strategy to lead in quantum technology. The company was also recognized as a "little giant," a designation for high-growth small and medium-sized enterprises in China with a focus on innovation.[34] From its inception, the company has focused on developing QKD systems, which have become critical for secure communications in sectors such as government, finance, and energy. This government backing, coupled with its strong academic roots, has enabled QuantumCTek to translate cutting-edge research into commercialized solutions that are now essential to China's quantum infrastructure.

While QuantumCTek emerged from pioneering research, its core mission is not about breaking new ground in quantum science, but rather about converting academic breakthroughs into practical, market-ready technologies. As deputy chairman of the company Zhao Yong is reported to have said, "Our primary task is to transform quantum communication from academic papers to real products and services, especially quantum key distribution, which is an important technology for information security."[35]

QuantumCTek's flagship product, its QKD system, has seen widespread adoption across China, particularly in sectors where secure communication is paramount. These include government agencies, financial institutions, and energy companies, all of which require the highest levels of data protection.[36] Notably, QuantumCTek has been instrumental in building a 46-node quantum network across Hefei, which integrates seamlessly into the Beijing-Shanghai Quantum Communication Backbone—China's largest and most advanced quantum communication network. This Hefei network, developed in collaboration with USTC and other institutions, secures critical data for local sectors such as government and finance, reinforcing the backbone's intercity connections. QuantumCTek's contributions highlight the company's pivotal role in fortifying China's national quantum infrastructure and advancing its ambitions for global leadership in quantum-secured communications.

QuantumCTek is also making strides in quantum computing. The company is involved in developing quantum chips, including the "Xiaohong" chip, a 504-qubit superconducting quantum chip that set a new record for the number of qubits in a superconducting quantum chip in China.[37] The Xiaohong chip is slated to match the performance of top global quantum computers, such as those from IBM, in important areas such as how long it can keep information stable (qubit lifetime), how accurately it processes quantum information (gate fidelity), and how complex the calculations it can handle (quantum circuit depth) are. But according to Chinese researchers working on the breakthrough, the chip is not about helping make the fastest quantum computer but instead about improving the systems that control and measure quantum computers.[38] By focusing on building and refining these control systems, researchers ensure that as quantum computers grow more powerful, they can be reliably managed and operated. This approach helps pave the way for quantum computers to handle real-world tasks more effectively in the future.

China Telecom, one of the state-backed telecom operators, is partnering with QuantumCTek to develop a quantum computer using the new Xiaohong chip.[39] This quantum computer will be accessible through a cloud platform developed by China Telecom's Quantum Group, allowing researchers across various fields to efficiently work on practical problems and algorithms. The collaboration is expected to accelerate the real-world application of quantum computing, making it more accessible and useful for a wide range of industries.

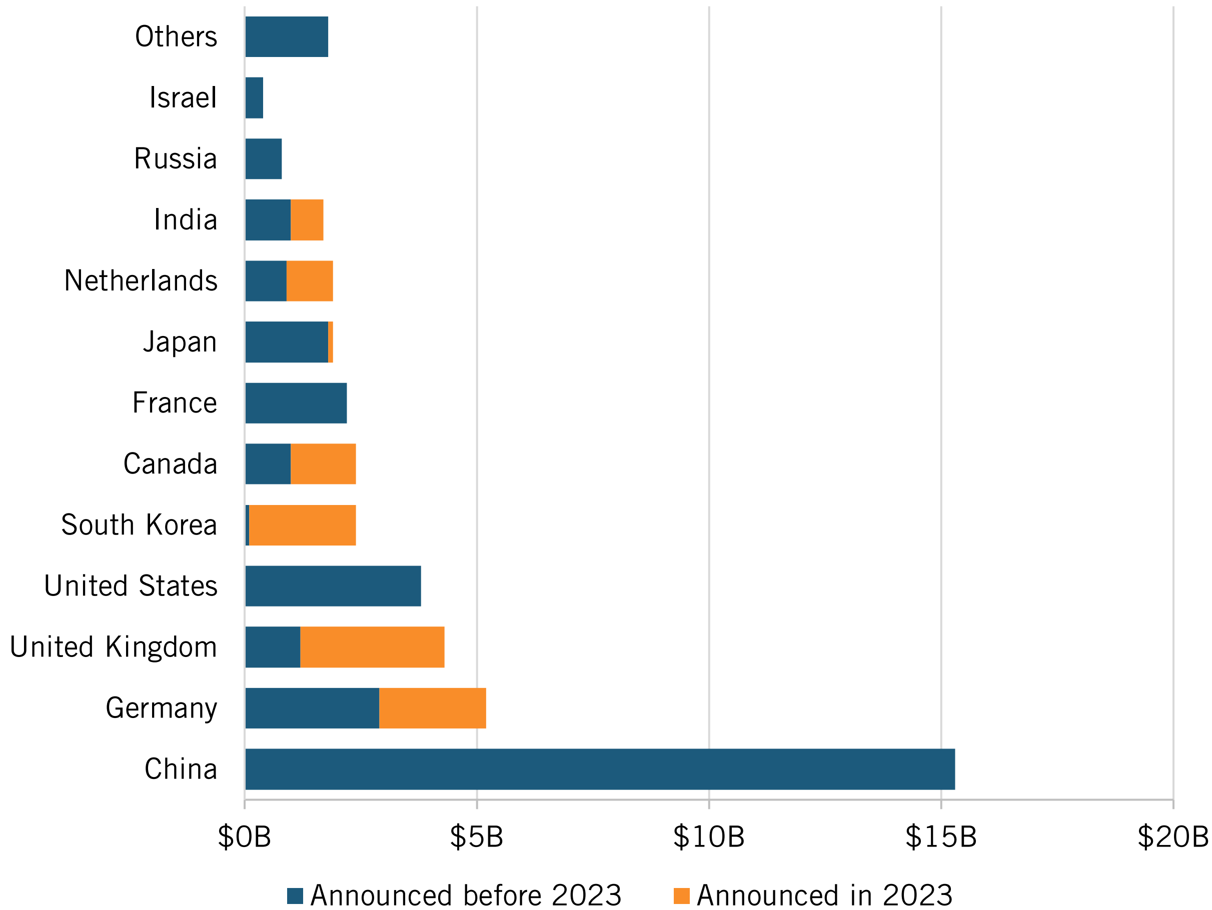
CHINA'S GOVERNMENT POLICIES SUPPORTING THE QUANTUM SECTOR

China's determination to lead in quantum technology by 2035 has long been at the core of President Xi Jinping's plan to enhance the country's global competitiveness. During the 19th National Congress of the Chinese Communist Party in 2017, Xi outlined an ambitious vision for China to surpass the West in technological development through a strategy of innovation-driven growth. Quantum science, with its potential to revolutionize fields such as computing, cryptography, and sensing, is seen as a crucial test of China's ability to achieve this goal.

China has embedded quantum technologies into its national strategy through the 13th and 14th Five-Year Plans, positioning quantum communications as vital to its long-term objectives. The 13th Five-Year Plan launched a "megaproject" aimed at securing breakthroughs in quantum communications and computing by 2030, including the expansion of national quantum infrastructure, the development of a quantum computer prototype, and the construction of a quantum simulator. The creation of the National Laboratory for Quantum Information Sciences, backed by over $1 billion, alongside a separate $10 billion investment in key projects such as the Micius satellite and the Beijing–Shanghai backbone, underscores China's ambition to dominate quantum technology.[40] In 2020, the Chinese president was reported to have urged the nation to accelerate its efforts in quantum technology, emphasizing the need for rapid commercialization to gain a competitive edge on the global stage. Speaking at a study session of the Communist Party's Central Committee, local reports noted that he "called for efforts to foster strategic emerging industries such as quantum communications to gain an upper hand in international competition and build new advantages for development."[41] These efforts have clearly paid off, as China has surged ahead as the global leader in quantum communications.

China's commitment to quantum technology is backed by significant public funding, although the exact figures remain murky. Estimates suggest that China has investments exceeding $15 billion, far outpacing the United States, which has allocated around $3.8 billion (see figure 4).[42] However, the true extent of China's investment is difficult to pin down due to the opacity of its government spending. Some reports suggest that actual spending might be lower, reflecting a common pattern wherein ambitious funding goals in China are not always fully realized.[43] Despite the uncertainty, there is little doubt that China's financial commitment, whether fully realized or not, is positioning it as a formidable force in the global quantum race, potentially outstripping other nations in both ambition and scale.

Figure 4: Announced government investments in quantum research and commercialization around the world[44]



Building on the momentum from the 13th Five-Year Plan, the 14th Plan intensifies China's focus on quantum technology by laying out more specific and ambitious goals. It calls for the establishment of national laboratories dedicated to quantum information, a move designed to consolidate China's leadership in this critical field. The plan prioritizes the development of advanced quantum communication technologies across intra-city, inter-city, and free-space environments, alongside the creation of a general quantum computing prototype and a practical quantum simulator.[45] Additionally, it emphasizes breakthroughs in quantum precision measurement technology and the innovative application of quantum in key digital sectors. The 14th Plan also underscores the dual aim of enhancing both national defense and economic strength through quantum advancements, ensuring that China not only leads in technology but also reaps broader strategic benefits.

Moreover, the Chinese Ministry of Industry and Information Technology (MIIT) identified quantum computing as a "future industry" within its broader industrial policy in a 2024 document it published, focusing on the development of fault-tolerant quantum computing technology and enhancing quantum software and cloud platforms.[46] It emphasized full-stack development, much like the approach Origin Computing takes, reflecting China's increasingly insular approach in which it aims to secure technological independence rather than rely on international partnerships.

The 2024 MIIT document also sets strengthening standards leadership as a goal for quantum, though China has been systematically strengthening its leadership in quantum for several years. In October 2021, China issued directives on how it plans to cement its role as a leader in setting international technological standards, including quantum technologies.[47] This effort gained further momentum in 2022 with the launch of the National Standardization Development Program (NSDP), a top-level initiative by the Chinese government that analyzed the global and domestic standards landscape and laid out specific steps to enhance China's standards-setting processes.

China's commitment to quantum technology is backed by significant public funding, although the exact figures remain murky.

Domestically, China is focusing on integrating standards setting directly into its quantum R&D projects. The NSDP mandates that researchers and scientists incorporate standards work as a core component of their projects, ensuring that standards are aligned with technological advancements from the outset. This approach is designed to create a seamless link between innovation and standardization, helping to drive the commercialization of quantum technologies more effectively. By embedding standards into the fabric of its quantum initiatives, China aims to bolster its domestic industry, making it more competitive globally. China's strategy also involves increasing its influence in international standards bodies such as ISO/IEC, where Chinese representatives have played leading roles, such as chairing the body's working group on quantum technologies.[48] Through these coordinated efforts, China is positioning itself to shape the future of quantum technology on the global stage, helping ensure that its standards and technologies become the global benchmarks.

WHAT SHOULD AMERICA DO?

The U.S. government should take proactive measures immediately to maintain its leadership position.

First and foremost, there is widespread consensus that increased funding is necessary. Indeed, one of the central recommendations from the National Quantum Initiative Advisory Committee (NQIAC), the federal agency composed of experts from academia, industry, and government, on how Congress should fund the next iteration of the NQI is that sustained and increased funding "will be necessary for our nation to win the race to realize the benefits of QIS."[49] The question becomes, How much funding is enough to accelerate U.S. QIS innovation and keep the nation competitive? That is difficult to answer, in part because, while the government's efforts to increase QIS R&D funding through the NQI Act are easily quantifiable, the benefits of these efforts are more difficult to quantitatively translate because there exist few consistent, comprehensive measures of how much U.S. QIS research has changed over time. It might be the case that NQIAC has this data as part of its assessment of the NQI program, but it has not publicly released this information. However, in its written comments to NQIAC in March 2023, the Energy Sciences Coalition, a broad-based coalition of over 100 organizations representing scientists, engineers, and mathematicians in universities and industry and national laboratories, recommended "at least $675 million each year over five years from FY 2024 through FY 2028."[50] Congress should reauthorize the NQI Act and appropriate at least this much per year (in addition to the CHIPS funding) for FY 2024 to FY 2028.[51] To ensure U.S. leadership in quantum, Congress should fund all the activities in the NQI Act at the authorized level.

While China bets on going it alone, the United States should build a winning strategy through deep partnerships with nations that bring complementary strengths to the table.

Now, securing this amount might be a challenge because, as a member of the House Science, Space, and Technology Committee working on the NQI Act reauthorization noted in a 2023 Center for Data Innovation panel, "There are different parameters in this Congress than there were last year in the 116th [Congress] … I don't think that we're going to be seeing a CHIPS-like program."[52] Therefore, to better match the sheer scale of China's purported quantum R&D, the United States should coordinate funding efforts with allied nations. By pooling resources across a network of like-minded countries, the United States can target joint R&D initiatives that maximize each nation's strengths, creating a powerful bloc that drives innovation forward more effectively than any one country could on its own. This collaborative approach not only amplifies U.S. capabilities but also enhances the global impact of allied research efforts, ensuring a balanced and strategic advancement in quantum technologies.

Indeed, **the United States can turn China's insular approach to quantum technology into an Achilles' heel by embracing the power of collaboration with its allies.** While China bets on going it alone, the United States should build a winning strategy through deep partnerships with nations that bring complementary strengths to the table. U.S. allies possess distinct advantages in key areas of quantum technology that the United States can leverage to gain a strategic edge. Germany, for instance, excels in quantum sensing, with advanced research hubs such as the Munich Quantum Valley and a strong integration of industry and academia.[53] By tapping into these allied strengths, the United States and its partners can pool resources and expertise, ensuring leadership in the global quantum landscape and turning competitive pressures from China into opportunities for allied dominance. These allies also contribute diverse ecosystem structures that can further enhance the U.S. quantum strategy. In Australia and the United Kingdom, start-ups drive the quantum industry, while Germany's and Japan's quantum sectors are led by large, established corporations with strong government R&D ties.[54] By combining the innovation of start-ups with the stability of larger companies, the United States and its allies can build a robust, resilient quantum ecosystem. Furthermore, building a secure and resilient quantum supply chain is critical. Working closely with allied nations to identify and safeguard key suppliers of components and materials can fortify the U.S. position against potential disruptions. This cooperative strategy leverages the strengths of allies with specialized expertise and resources, ensuring that the United States and its partners maintain a steady, reliable flow of essential quantum technology inputs.

The United States should also move more quickly to expedite the commercialization of the quantum industry. China is not the only country doing this. The United Kingdom, for instance, has established a Commercializing Quantum Technologies challenge that provides around £174 million ($214 million) of government funding, supported by £390 million ($480 million) in funding from industry, for industry-led projects that address four themes of the government's industrial strategy: clean growth, aging society, the future of mobility, and artificial intelligence. As of fall 2022, this challenge had provided funding for 139 projects led by U.K.-registered businesses.[55] Congress should establish and provide $200 million to fund a program that encourages companies and developers to come up with quantum solutions for health care, mobility, and energy challenges in the public sector. For example, firms may come up with innovative ideas that include using quantum to optimize traffic flow and the transportation of goods. By challenging industry to develop innovative solutions for public sector needs from the demand side, the government is offering up U.S. cities as successful first customers, thereby increasing market demand for nascent near-term quantum computing technologies and enabling companies to create competitive advantage in the market.[56]

The United States should approach quantum technology as a critical national security and economic imperative, not just a scientific pursuit. While the United States fosters open innovation, China's protectionist stance on its own advances creates an asymmetric knowledge-sharing environment. This imbalance risks the United States becoming a global quantum research hub while China dominates commercialization. To address this, our report "Why the United States Needs to Support Near-Term Quantum Computing Applications" recommends several strategies to bridge the critical gap between cutting-edge research and market-ready applications in quantum technologies, including that Congress should establish a national quantum research cloud; the Office of Science and Technology Policy should issue a federal quantum challenge to encourage agencies to explore quantum computing applications; and Congress should establish a program that challenges companies to develop innovative quantum solutions for public sector problems.[57]

While China is increasingly assertive in setting international standards for quantum technologies, the United States should avoid overreacting by rushing to impose its own standards prematurely.[58] Quantum technology is still in its early stages, and pushing for rigid standards too soon could stifle innovation and lock in limitations before the technology has fully matured. The United States should focus on organic, industry-driven development of standards that evolve naturally as the technology progresses. Over-involvement by the government in standards-setting could mirror the very practices the United States criticizes in China, potentially leading to unnecessary conflicts and hindering the global advancement of quantum technologies. The United States should instead support a flexible, collaborative approach to standards that encourages innovation and adapts to technological breakthroughs as they emerge.

Finally, while export controls are vital for safeguarding quantum technologies from misuse, policymakers should apply them judiciously to avoid hindering both innovation and international collaboration. Quantum R&D is a global endeavor, with advancements and supply chains spread across multiple countries. Imposing broad, unilateral export controls could backfire, isolating the United States from key global partnerships and stifling the flow of talent and ideas crucial for progress. Instead, the United States should focus on targeted controls that address specific risks without broadly limiting the exchange of knowledge and components. These measures should be developed in close coordination with allies to ensure that they are both effective and aligned with global market dynamics. By striking a balance between security and collaboration, the United States can protect its interests while continuing to lead in quantum innovation.

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About the Authors

Hodan Omaar is a senior policy manager at ITIF's Center for Data Innovation. Previously, she worked as a senior consultant on technology and risk management in London and as an economist at a blockchain start-up in Berlin. She has an M.A. in Economics and Mathematics from the University of Edinburgh.

Martin Makaryan is a research assistant specializing in digital policy. He is a master's student at the School of Advanced International Studies (SAIS) at Johns Hopkins University where he specializes in security and strategy. He holds a B.A. in Political Science and Global Studies from UCLA.

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ENDNOTES

1. Edward Parker et al., *An Assessment of the U.S. and Chinese Industrial Bases in Quantum Technology* (RAND, February 2022), https://www.rand.org/pubs/research_reports/RRA869-1.html.
2. Brandon Kirk Williams, "The Innovation Race: US-China Science and Technology Competition and the Quantum Revolution" in *2022-2023 Wilson China Fellowship: Understanding China Amid Change and Competition*, edited by Lucas Myers (Washington, D.C.: Wilson Center, 2023), https://www.wilsoncenter.org/publication/innovation-race-us-china-science-and-technology-competition-and-quantum-revolution.
3. Parker et al., *U.S. and Chinese Industrial in Quantum Technologies.*
4. "Quantum Technology Monitor 2023" (McKinsey and Company, April 2023), https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/quantum%20technology%20sees%20record%20investments%20progress%20on%20talent%20gap/quantum-technology-monitor-april-2023.pdf.
5. *Strategic Research and Industry Agenda 2030,* European Quantum Flagship (February 2024), https://qt.eu/media/pdf/Strategic-Reseach-and-Industry-Agenda-2030.pdf.
6. Berenice Baker, "Baidu Ends Quantum Operations," *IoT World Today,* January 4, 2024, https://www.iotworldtoday.com/quantum/baidu-ends-quantum-operations.

7. Ed Gent, "Alibaba and Baidu Cash Out on Quantum Computing Stakes," *IEEE Spectrum,* February 14, 2024, https://spectrum.ieee.org/china-quantum-computer-alibaba-baidu.

8. ASPI's Critical Technology Tracker: the global race for future power, (Australia Strategy Policy Institute, March 2023), https://www.aspi.org.au/report/critical-technology-tracker.

9. Elsa B Kania and John Costello, "Quantum hegemony? China's ambitions and the challenge to US innovation leadership" (Center for a New American Security, September 2018), https://www.cnas.org/publications/reports/quantum-hegemony.

10. Rachel Courtland, "China's 2,000-km Quantum Link Is Almost Complete," *IEEE Spectrum,* October 26, 2016, https://spectrum.ieee.org/chinas-2000km-quantum-link-is-almost-complete.

11. Karen Kwon, "China Reaches New Milestone in Space-Based Quantum Communications," *Scientific American*, June 25, 2020, https://www.scientificamerican.com/article/china-reaches-new-milestone-in-space-based-quantum-communications.

12. Courtland, "China's 2,000-km Quantum Link Is Almost Complete."

13. "QKD: Part of a Defense-In-Depth Strategy," Quantum Economic Development Consortium, May 30, 2024, https://quantumconsortium.org/qkd-part-of-a-defense-in-depth-security-strategy/.

14. Iulia Georgescu, "Trapped ion quantum computing turns 25," *Nature*, May 18, 2020, https://www.nature.com/articles/s42254-020-0189-1.

15. Zhang Tong, "China sells quantum chips to Middle East and Western countries in show of growing influence in sector," *South China Morning Post,* November 30, 2023, https://www.scmp.com/news/china/science/article/3243268/china-sells-quantum-chips-middle-east-and-western-countries-show-growing-influence-secotr.

16. ASPI's Critical Technology Tracker; Greg Austin, "Quantum Sensing: Comparing the United States and China" (The International Institute for Strategic Studies, February 2024), https://www.iiss.org/en/research-paper/2024/02/quantum-sensing-comparing-the-united-states-and-china./

17. *Full Committee Hearing: Advancing American Leadership in Quantum Technology before the House Committee on Science, Space, and Technology,* 118th Congress, June 7, 2023*,* (Statement of Dr. Celia Merzbacher, Executive Director of Quantum Economic Development Consortium), https://democrats-science.house.gov/imo/media/doc/Merzbacher-%20Testimony.pdf.

18. Juljan Krause, "The Quantum Race: U.S.-Chinese Competition for Leadership in Quantum Technologies," University of California Institute on Global Conflict and Cooperation, February 28, 2024, https://ucigcc.org/publication/the-quantum-race-u-s-chinese-competition-for-leadership-in-quantum-technologies/.

19. Stephen Chen, "Chinese scientists say cheap SQUID submarine detector is world's most sensitive," *South China Morning Post,* January 3, 2024, https://www.scmp.com/news/china/science/article/3247126/chinese-scientists-say-cheap-squid-submarine-detector-worlds-most-sensitive.

20. "Quantum magnetometers detect smallest material defects at an early stage," Fraunhofer Institute for Applied Solid State Physics IAF, January 23, 2024, https://phys.org/news/2024-01-quantum-magnetometers-smallest-material-defects.html.

21. Quantum Technology Monitor, McKinsey.

22. Ibid.

23. Xu Jing, "China's Hefei builds world-leading high-tech zone," *Los Angeles Post,* originally in *People's Daily*, November 28, 2022, https://lapost.us/?p=54856.

24. Ma Si, "Vital business starts at subatomic level," *China Daily,* March 30, 2022, https://global.chinadaily.com.cn/a/202203/30/WS6243baa9a310fd2b29e541f6.html.

25. Key Laboratory of Quantum Information, School of Physical Sciences, University of Science and Technology of China, https://en.physics.ustc.edu.cn/7852/listm.htm.
26. Parker et al., *U.S. and Chinese Industrial in Quantum Technologies.*
27. Ibid.
28. ASPI's Critical Technology Tracker.
29. "A Portrait of the Global Patent Landscape in Quantum Technologies" (European Quantum Industry Consortium, January 2024), https://www.euroquic.org/wp-content/uploads/2024/03/QuIC-White-Paper-IPT-January-2024.pdf.
30. Ibid.
31. Ibid.
32. Zhang Weilan, "US blockades won't hinder China's quantum computing technology development: leading scientist," *Global Times,* July 26, 2024, https://www.globaltimes.cn/page/202407/1316805.shtml.
33. Dannie Peng, "China's top quantum physicist Pan Jianwei named Royal Society fellow, days after US sanctions target Chinese sector," *South China Morning Post,* May 17, 2024, https://www.scmp.com/news/china/science/article/3263118/chinas-top-quantum-physicist-pan-jianwei-named-royal-society-fellow-days-after-us-sanctions-target.
34. Si, "Vital business starts at subatomic level."
35. Ibid.
36. James Dargan, "9 Leading Chinese Quantum Computing Companies (2022)," *The Quantum Insider,* April 20, 2021, https://thequantuminsider.com/2021/04/20/9-companies-leading-the-quantum-technologies-race-in-china/.
37. "Chinese Research Team has Delivered Xiaohong, a 504-Qubit Chip, the Largest Superconducting Quantum Chip in China," *Quantum Computing Report* by Global Quantum Intelligence, April 27, 2024, https://quantumcomputingreport.com/chinese-research-team-has-delivered-xiaohong-a-504-qubit-chip-the-largest-superconducting-quantum-chip-in-china/.
38. "China Sets Pace with 504-Qubit Quantum Chip, Xiaohong. Opens Access to Global Users," *Quantum Zeitgeist,* April 27, 2024, https://quantumzeitgeist.com/504-qubit-quantum-chip-xiaohong/.
39. Ibid.
40. James Dragan, "15 Leading Quantum Computing Countries with National Initiatives," *The Quantum Insider,* April 29, 2021, https://thequantuminsider.com/2021/04/29/leading-quantum-computing-countries/.
41. Simon Sharwood, "Xi Jinping tells China to get busy quickening quantum everything to build 'new advantages for development,'" *The Register,* October 19, 2020, https://www.theregister.com/2020/10/19/china_quantum_ambition/.
42. "Betting Big on Quantum," McKinsey and Company, September 13, 2022, https://www.mckinsey.com/featured-insights/sustainable-inclusive-growth/chart-of-the-day/betting-big-on-quantum.
43. Sydney J. Freedberg Jr., "China's investing billions in quantum R&D, but is Beijing making some bed bets?" *Breaking Defense,* February 5, 2024, https://breakingdefense.com/2024/02/chinas-investing-billions-in-quantum-rd-but-is-beijing-making-some-bad-bets/.
44. Michael Bogobowicz et al, *Steady progress in approaching the quantum advantage* (McKinsey and Company, April 2024), https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/steady-progress-in-approaching-the-quantum-advantage.

45. “Outline of the People’s Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035,” *Xinhua News Agency,* translated by Center for Security and Emerging Technology (CSET) at Georgetown University, May 12, 2021, https://cset.georgetown.edu/wp-content/uploads/t0284_14th_Five_Year_Plan_EN.pdf.
46. Chinese Ministry of Industry and Information Technology et al., “Implementation Opinions of Seven Ministries Including the Ministry of Industry and Information Technology on Promoting the Innovative Development of Future Industries,” February 12, 2024, translated by Center for Security and Emerging Technology (CSET) at Georgetown University, https://cset.georgetown.edu/publication/future-industry-implementation-opinions/.
47. “China raising the ante on standards setting,” Quantum Economic Development Consortium, July 2022, https://quantumconsortium.org/blog/china-raising-the-ante-on-standards-setting/.
48. Nigel Cory, “The Biden Administration Overreacts Responding to China’s Role in Setting Standards for Quantum Technologies” (ITIF, July 29, 2024), https://itif.org/publications/2024/07/29/the-biden-administration-overreacts-in-responding-to-china-s-role-in-setting-standards-for-quantum-technologies/.
49. “National Quantum Initiative Advisory Committee: Notice of open meeting,” Federal Register, March 2, 2023 (comments were made by NQIAC members in the public meeting on March 24, 2023), https://www.federalregister.gov/documents/2023/03/06/2023-04518/national-quantum-initiative-advisory-committee.
50. National Quantum Initiative Advisory Committee (NQIAC) Written Comments from Energy Sciences Coalition, March 14, 2023, https://www.quantum.gov/wp-content/uploads/2023/03/NQIAC-2023-03-24-Written-Comments.pdf.
51. Hodan Omaar, “The U.S. Approach to Quantum Policy” (Center for Data Innovation, ITIF, October 2023), https://www2.datainnovation.org/2023-us-quantum-policy.pdf.
52. Center for Data Innovation panel (17:00), “What Should Congress Include in The Next National Quantum Initiative Act?” May 2, 2023, https://datainnovation.org/2023/05/what-should-congress-include-in-thenext-national-quantum-initiative-act/.
53. Edward Parker et al., *An Assessment of U.S.-Allied Nations’ Industrial Bases in Quantum Technology* (RAND, November 2023), https://www.rand.org/pubs/research_reports/RRA2055-1.html.
54. Ibid.
55. UK Research and Innovation (UKRI), UK Quantum Technologies Challenge (London: UKRI, 2023), https://www.ukri.org/wpcontent/uploads/2023/01/UKRI-03012023-Quantum_projects_brochure2022.pdf.
56. Hodan Omaar, “Why the United States Needs to Support Near-Term Quantum Computing Applications” (Center for Data Innovation, ITIF, April 2021), https://www2.datainnovation.org/2021-quantum-computing.pdf.
57. Ibid.
58. Cory, “The Biden Administration Overreacts.”