

Quantum Technologies and the Geostrategic Landscape: Implications for Finance and Central Banks



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Acronyms and Abbreviations

AI	artificial intelligence
AUKUS	Australia-United Kingdom-United States
BIS	Bank for International Settlements
CBDs	central bank digital currencies
CRQC	cryptographically relevant quantum computer
ETSI	European Telecommunications Standards Institute
G7	Group of Seven
IEC	International Electrotechnical Commission
IP	intellectual property
ISO	International Organization for Standardization
ITU	International Telecommunication Union
NIST	National Institute of Standards and Technology
OECD	Organisation for Economic Co-operation and Development
PPPs	public-private partnerships
PQC	post-quantum cryptography
QIRHM	quantum industry readiness heat map
QKD	quantum key distribution
QRNGs	quantum random number generators
R&D	research and development
SWIFT	Society for Worldwide Interbank Financial Telecommunication
SWOT	strengths, weaknesses, opportunities, threats
UAE	United Arab Emirates
VC	venture capital

Executive Summary

Quantum technologies (computing, sensing and communications) are emerging as a transformative frontier with profound implications for economic productivity, security and competitiveness, as well as financial stability. Like artificial intelligence (AI), quantum computing and its adjacent technologies have moved from theoretical promise to practical experimentation, attracting significant investment from both governments and private actors. For Group of Seven (G7) central banks, this rapid evolution demands close attention: quantum technologies' potential makes them both a national strategic asset for economic and security advantage, and a source of international systemic risk, given an assumed interface with financial markets, payment systems, economic surveillance and the regulatory environment.

Central banks have a distinct role in this emerging domain. Quantum technologies could impact the integrity of financial markets through both risk and opportunity channels. Quantum computing, in particular, elevates the stakes: cracking today's cryptographic standards could undermine global payment systems and digital assets, while quantum-enabled advances in optimization and modelling may dramatically enhance economic forecasting, monetary policy and planning. Achieving strong "quantum readiness" calls for early strategic planning, regulatory foresight and allied coordination.

In addition to the G7, this special report considers six other countries in its examination of the quantum landscape (see Figure 1). For G7 economies, a key question is whether to pursue an "allied acceleration" model of collaboration. Convergence with other technologies — including AI and the tokenization of assets on blockchain — will amplify the stakes for financial innovation, secure communications and cyberthreats.

Moving forward in uncertainty, G7 policy makers do have options. The special report's recommendations include establishing shared G7+ standards and practices for quantum cyber-resiliency and coordinating export controls and measures to avoid supply-chain vulnerabilities. Decision makers should also consider investing in cross-border research collaboration and complementarity to advance innovation and secure talent. Initial scenario planning suggests that while technological breakthroughs may unfold unevenly, the risks of inaction are high. The authors also recommend building quantum awareness and critical capacity for economic and financial decision makers, including those who are developing international regulatory frameworks and standards. With these policy directions, the G7 can help ensure that quantum technologies reinforce global stability and shared prosperity, rather than exacerbate global fragmentation and the existing digital divide between countries.

Introduction

Objectives

The goal of this special report is to provide a situational analysis of quantum technologies useful for senior G7 decision makers in finance and central banking. The analysis goes beyond the G7 countries to capture a broader global view. The special report examines the current landscape, as well as several scenarios. It outlines key implications for strategic planning and action for consideration by senior G7 policy leaders and others.

Figure 1: List of Countries Included in the Analysis

G7 Economies	Canada	OECD Economies	Australia	Other Economies	China
	France		The Netherlands		India
	Germany		South Korea		Russia
	Italy				
	Japan				
	United Kingdom				
	United States				

Source: Authors.

Notes: OECD = Organisation for Economic Co-operation and Development.

Quantum Technologies as a Strategic Frontier

On many levels, quantum technologies are clearly on the strategic frontier. While the exact form varies among the 13 countries assessed in this special report, all of them have identified quantum technology on their “list” of critical technologies. The growing strategic importance of quantum science and technology is also reflected in international collaboration trends: the OECD (2025b, 19) reported a 15 percent decline from 2018 to 2022 in quantum-related co-authored papers among the United States and EU member states, “possibly influenced by security-related policies impacting co-operation, even among like-minded partners.”

In some cases, countries have domestic legislative frameworks for managing the technologies identified, while others use policy guidelines. Each of these countries also has some form of “quantum strategy,” elements of which are examined in the section “Governance and Regulatory Frameworks” below. In the case of the G7 itself, leaders issued the “Kananaskis Common Vision for the Future of Quantum Technologies” in June 2025, recognizing their importance and acknowledging that “achieving quantum technologies’ full potential will require international collaboration between governments, researchers and industry to mobilize investments and optimize resources; advance research and commercialization; secure supply chains; facilitate access to infrastructure, talent and markets; align

adoption with shared interests and values; and create a trusted ecosystem to manage risks and unleash innovation” (G7 2025, 1).

More broadly, quantum technologies are emerging as strategic national assets.¹ Increasingly, this has led to the contours of quantum competition being shaped by three domains (Lewis and Wood 2023; Erixon et al. 2025; Omaar and Makaryan 2024; Mans 2025):

- **Leadership in dual-use (civilian and military) quantum capabilities:** commercial solutions that drive high economic growth² and next-generation defence platforms that strengthen a nation’s security posture.
- **Cyber-physical infrastructure:** secure financial networks³ and critical infrastructure monitoring.⁴
- **Technological sovereignty:** supply-chain resiliency (quantum-solution providers, components and materials),⁵ including related human capital and financial investment.

The implications for central banks and financial institutions range from the need to anticipate constraints on access to global quantum hardware/software and quantum talent, to regulatory challenges posed by the layered quantum technology stack. In addition, the opportunity to capture the potential benefits for innovation and productivity calls for preparatory measures in quantum education and experimentation and a balanced approach to enabling regulation in the financial sector. At the same time, jurisdictions that attract talent and investment while implementing proactive intellectual property (IP) strategies and start-up support are set to dominate early deployment of quantum solutions. Integration of quantum technology with the financial sector is accelerating, with notable efforts distributed across the G7 financial and banking sectors concentrated in quantum computing and quantum communication applications (see Appendix 1 for selected examples of quantum technology use cases in finance).

Framing the Basis of Quantum Technologies

Quantum physics (quantum mechanics) provides the theoretical basis to understand the fundamental nature of matter and energy. The first quantum revolution applied quantum knowledge to create the path-finding technologies of lasers, magnetic resonance imaging machines and transistors. The second quantum revolution, well under way, is focused on controlling and engineering individual quantum systems and harnessing quantum phenomena directly.⁶ This next wave

1 Strategic national assets are resources or capabilities that provide a decisive and enduring advantage to move forward at least one element of core national interest. The loss or compromise of a strategic asset is assumed to significantly weaken the power, and even sovereignty, of a nation.

2 Select examples range from solving problems that are challenging or intractable for classical computers, to novel medical diagnostics and personalized health care, to new materials discovery leading to new devices and applications.

3 Select examples include post-quantum cryptography (PQC) and satellite-driven quantum key distribution (QKD) (see www.nsa.gov/Cybersecurity/Quantum-Key-Distribution-QKD-and-Quantum-Cryptography-QC/).

4 The World Economic Forum’s white paper “Quantum Technologies: Key Strategies and Opportunities for Financial Services Leaders” elucidates potential use cases and benefits (World Economic Forum 2025).

5 Solution providers include, for example, third-party vendors that support quantum or quantum-safe technology deployment. Components include cryogenics, control systems and specialized manufacturing. Materials include, for example, indium, germanium, helium-3 and silicon 28.

6 Such as wave-particle duality, superposition, interference, quantum measurement, tunnelling and entanglement. For a description of quantum phenomena, see <https://uwaterloo.ca/institute-for-quantum-computing/outreach/quantum-101>.

promises quantum computers capable of solving problems that are intractable classically with speed-up advantage for select problems; quantum sensors with orders of magnitude improvements in sensitivity, selectivity or resource efficiency; and quantum communication that is provably secure from eavesdroppers.⁷ Box 1 illustrates the basics of quantum, what quantum technologies can do and their dual-use implications for society.

This special report is centred on three quantum technologies most relevant to finance and central banking: quantum computers, quantum communication and quantum sensing. Quantum computing (broadly defined) and quantum communication receive greater attention in this special report, reflecting their more advanced deployment stage in finance than quantum sensing, based on publicly disclosed reporting (see Appendix 1). An important consideration throughout this special report is the “readiness level” of each quantum technology,⁸ which varies based on its underlying physical modality and financial application.

Global Quantum Landscape: Key Drivers and Economic Stakes

Risks and Opportunities

Quantum Cybersecurity Risks

One of the most immediate concerns raised specifically by quantum computing is the vulnerability of current cryptographic systems to future quantum-enabled attacks, including the risk of “harvest now, decrypt later” strategies, whereby data is acquired today and stored, awaiting breakthroughs enabled by quantum algorithms deployed on quantum computers at scale. A sufficiently advanced quantum computer, or cryptographically relevant quantum computer (CRQC), could break widely used encryption schemes (for example, the Rivest-Shamir-Adleman algorithm, elliptic curve cryptography) that underpin everything from Society for Worldwide Interbank Financial Telecommunication (SWIFT) transactions to blockchain-based smart contracts. The National Institute of Standards and Technology (NIST) (2024) has finalized the first wave of PQC standards,⁹ and some governments are mandating cryptographic upgrades across critical infrastructure.

⁷ For a high-level description of quantum technologies and a technical description of quantum information science, see OECD (2025a) and Nielsen and Chuang (2000), respectively.

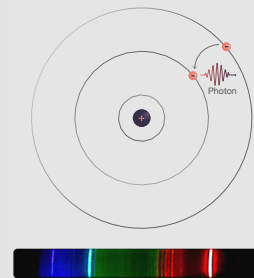
⁸ See Parker (2021), Geneva Science and Diplomacy Anticipator (<https://radar.gesda.global/topics/quantum-computing>), Krelina (2021) and Purohit et al. (2024) for a description of quantum technology readiness and associated timelines.

⁹ See <https://csrc.nist.gov/projects/post-quantum-cryptography>.

What Are Quantum Technologies?

Quantum science describes light and matter at the limits of classical physics. Modern advancements in quantum information science and technology use quantum systems to store, transmit, manipulate, and measure information with enhanced capabilities.

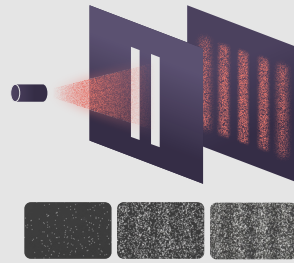
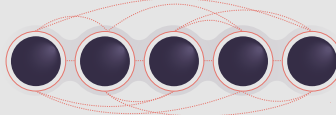
The rules of quantum science can seem strange, but they have been tested in more than 100 years of experiments. Unique properties harnessed in quantum technologies include:



Quantization
Quantum systems have countable (discrete) properties such as energy, often very precisely defined.

Visible spectrum of a hydrogen discharge tube. (Source: Wikimedia Commons)

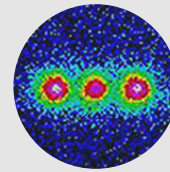
Entanglement
Multiple quantum systems can be in a joint superposition state, where individual components cannot be described without considering the whole system. This allows for correlations beyond what classical physics predicts.



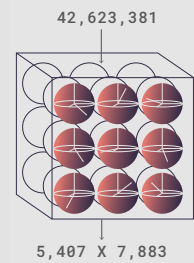
Interference pattern from a double-slit experiment with individual photons. (Source: Wikimedia Commons)

Interference and Superposition

Quantum systems can be in superposition states, which have uncertain properties. The probability of measuring certain outcomes may be amplified or cancelled out due to interference.



Fluorescence from three trapped beryllium ions illuminated with an ultraviolet laser beam. (Source: Wikimedia Commons)

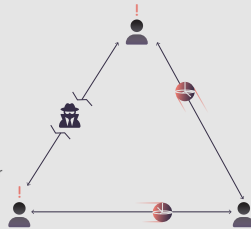


Quantum computers solve algorithmic problems with the addition of quantum operations empowered by interference and entanglement. This added power unlocks a new paradigm for computing that can tackle many problems in optimization, simulation, and mathematics more efficiently than today's computers, including some problems that modern supercomputers cannot solve effectively, such as factoring very large numbers.

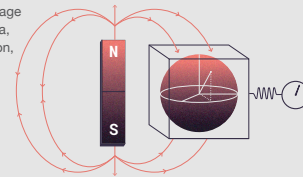
What Can Quantum Technologies Do?

Quantized systems such as atoms, photons, and superconducting circuits can all have quantum bits, or qubits, encoded into their properties. These systems can in principle do everything a classical computer could, but can also use quantum phenomena such as quantization, interference, and entanglement to manipulate information in previously unimaginable ways, with applications in computing, communication, sensing, and more.

Quantum communication improves how groups can accomplish tasks using quantum resources. This includes QKD, a cryptographic protocol that relies on quantization and the uncertainty principle, where measuring an individual quantum object changes its state. This allows us to detect whether an eavesdropper has interfered with our communication channel.



Quantum sensors take advantage of a variety of quantum phenomena, including sharp frequency resolution, sensitivity to external effects, and interference. Advanced quantum sensors may even have many quantum objects connected through entanglement.



How Can Quantum Impact Society?

Quantum technologies can be broadly deployed in three ways, reflecting their dual-use nature: quantum promise, quantum peril and quantum mitigation.

Quantum promise technologies improve our ability to accomplish tasks using new tools that rely on quantum science. These include using quantum computers for more efficient simulation of molecules and materials, accelerating research and development. They also include quantum sensors for tasks such as medical diagnostics, environmental monitoring, natural resource exploration, and navigation.



Quantum peril technologies challenge a nation's security, necessitating technological leadership to strengthen defence and military capabilities for effective deterrence. These include using quantum computing to hack existing cryptographic schemes and military applications of quantum sensing technologies.



Quantum mitigation technologies arise from our understanding of the quantum threat to counter its effect, protecting vulnerable systems to allow quantum promise technologies to benefit society. These may include tools such as cryptographic protocols, which are secure against even a quantum computer attack.



Implications for central banks and financial institutions include the need to transition to PQC well before the estimated date a CRQC becomes available; adopting a crypto-agile¹⁰ approach; and pursuing methods for complementary protection, including, for example, the implementation of proven symmetric key infrastructure techniques and emerging QKD technologies (Katwala 2025).¹¹ This layered cyber defence strategy aims to protect long-term confidentiality of sensitive information against fake digital signatures that may undermine the integrity and authenticity of digital transactions, and potentially the control of connected systems and devices (DuBose and Rao 2025). It would also ensure cross-border payment systems, clearing houses and financial data networks are quantum-resilient.

The application of AI techniques in combination with quantum computing and quantum-safe technologies may pose both risks and opportunities for long-term security and cryptographic resilience of digital infrastructure and blockchain-based digital assets, especially as digital financial infrastructure such as central bank digital currencies (CBDCs), stablecoins, tokenized assets and decentralized finance platforms scale globally (Hellstern and Yeniaras 2025).

Financial Data and Economic Impacts of Quantum Advancements

Quantum technologies (and quantum-inspired or quantum-adjacent technologies) are expected to significantly impact banking and finance, while reshaping the logic of financial computation, risk management and cryptographic infrastructure through optimization, modelling and machine-learning applications (Herman et al. 2022; Albareti et al. 2022; Dalzell et al. 2025). Selected areas of possible impact are:

- PQC and crypto-agility measures to safeguard critical financial systems, digital assets (including CBDCs) and banking infrastructure;
- quantum random number generators (QRNGs) for higher-assurance randomness to safeguard digital banking and payments infrastructure;
- quantum-secure communications through QKD and quantum-secure authentication and encryption;
- quantum sensors for obtaining highly detailed and sensitive data for monitoring the integrity and security of banking infrastructure;
- quantum clocks for precise and reliable timekeeping in financial markets to identify fraudulent activity;
- quantum algorithms for foreign-exchange reserves management;
- quantum-inspired and hybrid quantum-classical optimization algorithms for asset-liability management and option pricing (Patel et al. 2024);
- quantum annealers for small-scale portfolio optimization;
- quantum-secure authentication for payment systems (Goorden et al. 2014);

¹⁰ See NIST's overview of crypto agility (<https://csrc.nist.gov/projects/crypto-agility>).

¹¹ See Charbonneau and Mosca (n.d.) for a discussion of cyber-resilience in the quantum age, and the US National Security Agency (www.nsa.gov/Cybersecurity/Quantum-Key-Distribution-QKD-and-Quantum-Cryptography-QC/) on the limitations of QKD.

- quantum sensors for detecting anomalies in transactions (for example, fraudulent card readers) and for securing physical banking infrastructure (for example, detecting tampering with automated teller machines and unauthorized entry into a bank vault or data centre) (Gopasana, Ramesh and Sarkar 2025);
- quantum simulation and algorithms for risk modelling, forecasting (for example, predicting financial crashes) and recursive tasks (for example, as found in scenario analysis) (Herman et al. 2023; Ruddock 2021);
- variational quantum algorithms for simulating high-dimensional correlation structures and tail-risk events more effectively, supporting credit-risk and liquidity-stress testing (Das et al. 2025); and
- quantum-enhanced machine learning for improvements in anomaly detection, providing new tools for market surveillance and fraud detection.

Several consulting and research organizations have projected substantial macroeconomic value from quantum advances over the next decade and beyond: \$450–\$850 billion¹² annually by 2040 and \$1.3 trillion cumulative by 2035 (Bobier et al. 2024; Bogobowicz et al. 2023); and \$1 trillion in value creation by 2035 (Quantum Insider 2026). The G7 countries collectively represent the lion’s share of the global financial system, research and development (R&D) capacity and much of the digital infrastructure (World Bank 2025). The stakes are therefore higher for these economies, both in terms of gains from early adoption and risks from failing to capture early quantum advantages (see Table 1).

Table 1: Critical Economic Risks of Quantum Technologies

Risk Area	Description
Cybersecurity asymmetry	Nations that lag on PQC migration will face heightened systemic risk.
Economic concentration	Early movers could monopolize quantum applications in key sectors (for example, finance, defence, pharmaceuticals) and exacerbate the existing digital divide.
Brain drain and talent competition	Without proactive policies, some G7 economies risk losing quantum talent to non-allied countries.
Supply-chain choke points	Over-dependence on foreign suppliers for key quantum-service providers, components and materials could create economic vulnerabilities (Open Quantum Institute 2024).

Source: Authors.

¹² All dollar figures in US dollars.

Implications of Technological Convergence

Quantum technologies are advancing in parallel with other disruptive technologies, most notably AI and blockchain-based systems. Their combined multiplicative impact on the global economy, and particularly the financial system, will amplify the risks and opportunities discussed above. Specifically, the application of AI techniques may significantly help address quantum computing's biggest scaling challenges (Alexeev et al. 2024), and lead to other pathways (for example, AI for materials science, AI for robotics, AI for advanced manufacturing and so forth) that may recombine in interesting ways with quantum technology to broadly impact a wide array of applications. For example, low-Earth orbit space applications that have recently benefited from advancements in rocket-launch technology — and where quantum is already positioned to play an increasingly important role in secure communications and sensing, as noted in the Quantum Europe Strategy¹³ — is one area poised to be profoundly impacted by technological convergence.

With rapid advancement and diffusion, and through interlinked processes of combination, convergence and compounding, technology will create new “value chains” (Bheemaiah and Kuang 2025). As Mustafa Suleyman (2023, 55) writes in *The Coming Wave*, “For the first time core components of our technological ecosystem directly address two foundational properties of our world: intelligence and life.” Their interplay with other technologies, including robotics, may create powerful synergies that accelerate innovation and underscore the need for anticipatory governance to aid in steering the technology toward beneficial outcomes. Ultimately, strategic foresight grounded in technical understanding and regulatory agility will determine whether convergence becomes a source of resilience or vulnerability in the quantum age.

Governance and Regulatory Frameworks

Public communication through national strategies for quantum science and technology often provides significant signals for the approach that a country will take for governance and regulatory frameworks related to the sector. Discussions of governance, regulation and policy in the quantum domain are often characterized by a tension between economic and security framings (Murphy and Forrest 2025), and national strategies are no exception. On the one hand, some countries — including France (Gouvernement de France 2023), Germany (Federal Ministry of Education and Research 2023), Italy (Ministero dell'Università e della Ricerca 2025), Japan (Government of Japan 2021) and the United Kingdom (Department for Science, Innovation & Technology 2023) — have developed national strategies that incorporate security considerations alongside economic development efforts within the same framework. On the other hand, other countries have focused their national strategy on industrial matters and developed separate policy around national security implications. For example, Canada (Innovation, Science and Economic Development Canada 2022), China (Omaar and Makaryan 2024), India (Quantum Ecosystems Technology Council of India 2023), the Netherlands (Quantum Delta NL 2019, n.d.) and South Korea (Ministry of Science and ICT 2023a) have largely focused on industrial development

¹³ EC, *Quantum Europe Strategy: Quantum Europe in a Changing World, Communication from the Commission to the European Parliament and the Council*, COM(2025) 363 final, online: <<https://digital-strategy.ec.europa.eu/en/library/quantum-europe-strategy>>.

policy and security preparedness as separate policy areas. Given the widespread recognition of quantum technologies as dual use (Murphy, Forrest and Samson 2025), simultaneous consideration of both economic and security aspects must be prioritized to ensure that national approaches to governance and regulation of quantum offer a holistic perspective.

While national strategic documents provide a framework to identify and understand country-specific priorities in the quantum sector, the development of international agreements and partnerships at various scales and depths demonstrates the diverse range of institutional arrangements that are appearing to guide and govern the evolution of the sector. This research effort reviewed a range of bilateral agreements, institutional efforts, as well as unilateral and multilateral arrangements. While some state higher-level principles, others lock in regulatory commitments about present activities, and still others promise future engagement within a particular framework.

The European Union has been a significant actor, with the European Commission developing regulatory recommendations related to dual-use export controls, explicitly naming quantum technology alongside others.¹⁴ The development of a coordinated road map for member states' PQC transition further emphasizes the significant role of standard setting played by the European Union (NIS Cooperation Group 2025). In addition, quantum technologies are included in the multilateral Wassenaar Arrangement,¹⁵ a global agreement that brings together 42 participating countries that have agreed to standardized export controls on conventional arms as well as dual-use goods and technologies. The 2023 list of dual-use goods and technologies approved by Wassenaar Arrangement participating states includes quantum technologies, algorithms, cryptographic protocols and components (Wassenaar Arrangement Secretariat 2023). The participation of many major quantum states in this multilateral pact provides broad-based coherence to export policies.

Unilateral efforts take a variety of forms to support the development of regulatory frameworks around cryptographic and computing technologies. The Australia-United Kingdom-United States partnership (AUKUS) includes a commitment to the joint pursuit of advanced technological capabilities, including quantum computing (Brooke-Holland 2024). Cooperative efforts between security agencies, central banks and other government organizations have focused on the joint development of advanced cryptographic protocols that can subsequently inform regulatory standards.¹⁶ Partnership agreements between public research agencies further promote the integration of quantum ecosystems internationally.¹⁷ Although not all research efforts will directly lead to regulatory changes, their development often relies on existing partnership and facilitating policy frameworks.

14 EC, *Commission Recommendation (EU) 2021/1700 of 15 September 2021 on internal compliance programmes for controls of research involving dual-use items under Regulation (EU) 2021/821 of the European Parliament and of the Council setting up a Union regime for the control of exports, brokering, technical assistance, transit and transfer of dual-use items*, OJ, L 338/1, online: <<https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:L:2021:338:FULL&from=EN>>.

15 *Wassenaar Arrangement*, 12 July 1996, online: <www.wassenaar.org/the-wassenaar-arrangement/>.

16 See, for example, the joint project on PQC between the Banque de France and the Monetary Authority of Singapore (Banque de France 2024) or the QKD position paper released by the French Cybersecurity Agency, Federal Office for Information Security, Netherlands National Communications Security Agency and Swedish National Communications Security Authority (2024).

17 For example, the Natural Sciences and Engineering Research Council of Canada's agreements with the US National Science Foundation (see www.nserc-crsng.gc.ca/Innovate-Innover/NSERC-NSF-CRSNG_eng.asp) and France's Agence nationale de la recherche (see www.nserc-crsng.gc.ca/Innovate-Innover/ANR-ANR/index_eng.asp).

Table 2 summarizes the broad consensus across the G7 relating to governance and regulatory frameworks. When it comes to quantum technology, all states have a public national strategy, enforce export controls and participate in the Wassenaar Arrangement. Although the level of integration with the international system through minilateral or bilateral initiatives varies from state to state, all are engaged to a certain extent. Efforts within the G7 to continue coordinating quantum policy conversations can draw on these broad commitments to governance and regulation of the industry. The “national strategy” and “export controls” dimensions of the quantum industry readiness heat map (QIRHM) (see Appendix 2), consider the strength of these measures across various countries, including their implementation maturity, funding and oversight, and multilateral alignment.

Table 2: G7 Governance and Regulatory Frameworks

Country	National Strategy	Export Controls	Wassenaar Arrangement	Selected Minilateral or Bilateral Involvement
Canada	Yes	Yes	Yes	<ul style="list-style-type: none"> • BIS Working Group on CBDC • EU-Canada Digital Partnership Council (Prime Minister of Canada 2025) • Canada-Japan Memorandum of Cooperation
France	Yes	Yes	Yes	<ul style="list-style-type: none"> • European Union • EU-Canada Digital Partnership Council • EU-Japan Digital Partnership Council (Digital Agency 2025) • France-US Joint Cooperation Agreement
Germany	Yes	Yes	Yes	<ul style="list-style-type: none"> • European Union • EU-Canada Digital Partnership Council • EU-Japan Digital Partnership Council
Italy	Yes	Yes	Yes	<ul style="list-style-type: none"> • European Union • EU-Canada Digital Partnership Council • EU-Japan Digital Partnership Council
Japan	Yes	Yes	Yes	<ul style="list-style-type: none"> • BIS Working Group on CBDC • EU-Japan Digital Partnership Council • Canada-Japan Memorandum of Cooperation • Japan-Denmark Memorandum of Understanding • UK-Japan Memorandum of Cooperation

Country	National Strategy	Export Controls	Wassenaar Arrangement	Selected Minilateral or Bilateral Involvement
United Kingdom	Yes	Yes	Yes	<ul style="list-style-type: none"> • AUKUS • BIS Working Group on CBDC • UK-Japan Memorandum of Cooperation • US-UK Technology Prosperity Deal
United States	Yes	Yes	Yes	<ul style="list-style-type: none"> • AUKUS • BIS Working Group on CBDC • France-US Joint Cooperation Agreement • US-Netherlands Statement of Cooperation • US-UK Technology Prosperity Deal

Source: Authors.

Note: BIS = Bank for International Settlements.

A specific gap in terms of global governance and regulation of direct relevance to this special report has been the emergent domain of quantum threats toward digital assets and infrastructures. Although policy actors and academic experts have issued growing calls to recognize these threats, global coordination has been hampered by inconsistent definitions and policy goals (World Economic Forum 2023, 2024a, 2024b). Broader academic and policy commentary on digital assets and CBDCs has highlighted the significance of further cooperation to build resilience within the financial system as quantum threats emerge (Nili, Patterson and Dukatz 2024; Perrazzelli 2024), particularly to counter specific threats to blockchain technologies (Kearney and Perez-Delgado 2021), certificates (Vermeer et al. 2024) and digital signatures (Tan, Szalachowski and Zhou 2022).¹⁸ The European Union has led efforts to harmonize digital asset regulations through the Markets in Crypto-Assets Regulation and the Digital Operational Resilience Act.¹⁹ The BIS's expert working group on CBDCs has been a leading voice on governance and regulation, providing system-level guidance on the development of the technology (BIS 2020), as well as raising more specific considerations on the necessity of PQC resilience within CBDC systems (BIS 2024b, 8). There is a certain degree of fortuitous timing at play, as CBDCs and quantum-resilient protocols are likely to co-emerge, offering opportunities to dovetail these efforts (Arora et al. 2025). However, the patchwork approach to regulation of this space poses significant challenges to the development of a coherent framework to build international resilience against quantum threats to the financial system.

¹⁸ Threats to digital signatures have also been raised in Canada by the Office of the Superintendent of Financial Institutions (see www.osfi-bsif.gc.ca/en/risks/risks-arising-digital-innovations-canadian-financial-industry) and in the United Kingdom by the National Cyber Security Centre (2020).

¹⁹ Regulation (EU) 2023/1113 of the European Parliament and of the Council of 31 May 2023 on information accompanying transfers of funds and certain crypto-assets and amending Directive (EU) 2015/849, OJ, L 150/1, online: EUR-Lex <<https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1113>>.

Quantum Readiness and Priority Actions

As quantum capabilities expand, understanding where countries stand is crucial for situational awareness, strategic planning and cooperative governance. In this section, the authors present a consolidated analysis of the quantum readiness of G7 economies and other key countries, with a focus on their ability to drive, absorb and govern quantum innovation in the financial services sector.

Quantum technologies are inherently dual use in nature. Their broad applications for both civilian and defence challenges, reliance on deep talent pipelines and potential to disrupt cybersecurity, finance and supply chains make them critical levers of national power. However, the readiness to leverage quantum varies not only by the quantum technology under consideration (Purohit et al. 2024) but also widely across countries, driven by divergent levels of research intensity, industrial capacity, regulatory agility and workforce capacity.

Assessment Framework

To systematically evaluate how prepared leading global economies are to harness these capabilities, this special report employs a structured assessment framework based on four core transmission conduits of quantum's transformative potential (see Table 3).

These conduits function as the pillars through which scientific progress becomes economic infrastructure and financial utility. They serve two purposes: as a strategic lens for governments and central banks to evaluate their own national positioning, and as a comparative tool for situational awareness across the G7 and other strategically relevant economies.

Each conduit captures a distinct set of enablers that determine whether a country can generate, scale, govern and apply quantum technologies effectively.

Therefore, countries are assessed not just on individual pillars but also on their conduit coherence — the degree to which strengths across research, application, governance and talent are mutually reinforcing. Appendix 2 provides a detailed QIRHM that assesses the 13 countries in this analysis across these conduits, offering insights into the global landscape of quantum readiness.

Analysis: Quantum Readiness in G7+ Economies

To translate the conduit-based framework into actionable insights, the authors consolidated their findings into a strengths, weaknesses, opportunities and threats (SWOT) analysis (see Table 4; see Appendix 5 for a comprehensive list of sources). This highlights comparative strengths and weaknesses across G7 and other major economies while mapping opportunities and threats that will shape strategic planning.

Table 3: Core Transmission Conduits and Key Variables

Conduit	Focus	Key Variables
A. Technological and research capabilities	Scientific and technical capacity to generate quantum breakthroughs and translate them into deployable systems.	<p>A.1. R&D funding:</p> <ul style="list-style-type: none"> Measures total national investment (public and private) in quantum R&D, including direct government programs, university funding, industry consortia and defence-related initiatives. Tracks both absolute and GDP-adjusted levels. See Appendix 3 for a comparison of public and private funding in quantum technologies across the 13 countries included in this analysis. <p>A.2. National quantum labs:</p> <ul style="list-style-type: none"> Assesses the number, scale and mandate of publicly funded or semi-autonomous quantum research institutions, including whether they serve as open-access hubs, defence labs or public-private partnerships (PPPs) connecting academia and industry. <p>A.3. Publications and citations:</p> <ul style="list-style-type: none"> Evaluates both quantity and quality of research output, using bibliometric data (publication count, citation index and impact factor). Adjusted for population and GDP to indicate research efficiency and influence in the global quantum community. See Appendix 4 for representative quantum indices that capture relevant indicators for the key variables above.
B. Applications and industrial integration	Degree to which quantum technologies are absorbed by industry and aligned with financial and digital strategies.	<p>B.1. Start-up ecosystems:</p> <ul style="list-style-type: none"> Captures the number, maturity and funding of quantum-focused start-ups. Includes incubator and accelerator support mechanisms. <p>B.2. Pilots in financial services:</p> <ul style="list-style-type: none"> Tracks publicly disclosed quantum pilot projects or proofs-of-concept in banking, securities, insurance or payments, covering applications such as PQC, optimization and risk simulation. Includes central bank, regulator or private-sector participation. See Appendix 1 for select deployment cases for quantum in finance. <p>B.3. Supply-chain participation:</p> <ul style="list-style-type: none"> Measures a country's role across the full quantum hardware/software supply chain, including domestic production (for example, cryogenics, lasers, semiconductors, photonics); international participation in allied manufacturing networks or component-sourcing partnerships; and access to rare earth elements and exotic materials that are deemed necessary for the development of quantum technology. <p>B.4. Industrial strategies:</p> <ul style="list-style-type: none"> Evaluates the degree to which quantum technologies are embedded in broader national innovation, digital economy and industrial policies (for example, the Fourth Industrial Revolution, fintech, cybersecurity). Includes explicit references to finance, trade and critical infrastructure policies. <p>B.5. Patents and venture capital:</p> <ul style="list-style-type: none"> Measures innovation activity through patent filings, licensing and venture capital (VC) investment in quantum start-ups. Includes both domestic investors and foreign capital inflows supporting quantum commercialization. See Appendix 4 for representative quantum indices that capture patent-related indicators.

Conduit	Focus	Key Variables
C. Governance and regulation	National policy, regulation and security frameworks to manage quantum's risks and enable adoption.	<p>C.1. National strategies:</p> <ul style="list-style-type: none"> Identifies the existence, scope and implementation maturity of formal government quantum strategies or road maps. Includes dedicated funding mechanisms, interministerial coordination and oversight structures. <p>C.2. Export controls:</p> <ul style="list-style-type: none"> Evaluates the presence and scope of export control regulations for dual-use quantum technologies (hardware and IP). Considers alignment with multilateral regimes such as the Wassenaar Arrangement or AUKUS agreements. <p>C.3. Standards participation:</p> <ul style="list-style-type: none"> Measures involvement in international standard-setting bodies (ISO/IEC, ITU, ETSI and CEN-CENELEC Joint Technical Committee 22) and influence on emerging PQC, QKD and interoperability frameworks. Captures leadership roles and joint working group participation. <p>C.4. PQC readiness:</p> <ul style="list-style-type: none"> Assesses the extent to which PQC standards are being adopted in public institutions, critical infrastructure and financial systems. Includes pilot adoption, regulatory guidance and public-private readiness programs. <p>C.5. Regulatory coordination:</p> <ul style="list-style-type: none"> Examines the degree of alignment between quantum governance bodies (science/industry ministries) and financial or cybersecurity regulators. Includes joint task forces, working groups and coordinated migration timelines.
D. Talent and workforce	Availability and sustainability of skilled human capital in quantum sciences and applications.	<p>D.1. Quantum-skilled professionals:</p> <ul style="list-style-type: none"> Measures the size and composition of the quantum-capable workforce (scientists, engineers, software developers), benchmarked per capita and across sectors (academic, industrial, defence, financial). <p>D.2. Education and training pipelines:</p> <ul style="list-style-type: none"> Tracks the existence and scale of formal education programs (undergraduate to Ph.D.), technical certifications, national scholarship schemes and industry partnerships for workforce development. <p>D.3. Student retention:</p> <ul style="list-style-type: none"> Evaluates retention rates of foreign students trained in quantum or related fields, capturing migration flows post-graduation as an indicator of domestic innovation absorption capacity. <p>D.4. Immigration and mobility:</p> <ul style="list-style-type: none"> Assesses policies and visa regimes supporting recruitment of foreign talent, participation in international mobility networks and exchange programs fostering global collaboration.

Source: Authors.

Note: ETSI = European Telecommunications Standards Institute; IEC = International Electrotechnical Commission; ISO = International Organization for Standardization; ITU = International Telecommunication Union.

Table 4: SWOT Analysis of G7+ Economies

Strengths	Weaknesses
Strong R&D hub in the United States, with distributed strengths across the balance of G7+ economies	Uneven PQC readiness; lack of migration timelines in many countries
Established participation in global standards-setting bodies	Talent bottlenecks, especially in applied financial sector quantum skills
Early pilots in quantum-safe communications and optimization	Weak industrial integration in smaller economies; reliance on foreign supply chains
Growing policy awareness of quantum threats to digital assets and payment systems	Limited regulatory coordination between technology and finance authorities
Opportunities	Threats
Align national quantum strategies with financial sector modernization	Non-allied country achieves CRQC first-mover status, accelerating cyber risks
Expand cross-border quantum research and infrastructure partnerships under a PPP model	Supply-chain choke points in one or more areas (for example, quantum-solution providers, components, materials)
Adopt a layered quantum cyber-resiliency strategy and integrate PQC into CBDC, stablecoin and tokenized asset frameworks from inception	Fragmentation of international standards and lack of interoperability and multilateral governance
Leverage technological convergence for financial advantage	Weaponization of quantum technologies for strategic national objectives

Source: Authors.

This SWOT analysis illustrates that readiness for quantum adoption is uneven across the G7+. Global leaders such as the United States benefit from the strongest research ecosystems, significant public and private investment, and growing industrial integration. These countries are most active in translating research strength into early pilots and commercial applications, especially in quantum-safe communications and optimization tools (Ruane et al. 2025). However, even among these leaders, persistent weaknesses in workforce development (Mohr et al. 2022), applied financial sector skills (Puel and Mikołajczak 2025) and regulatory coordination pose risks to longer-term resilience (Department for Science, Innovation & Technology and Regulatory Horizons Council 2024). Without targeted interventions to expand and retain talent pipelines and increase the depth of professional expertise by improving collaboration between technology agencies and financial regulators, the pace of innovation could outstrip the capacity of institutions (public and private) to govern and secure it effectively.

Opportunities lie in leveraging multilateral and cross-border initiatives to fill these gaps. Collaborative frameworks, whether through the G7, BIS or multilateral alliances, can support joint migration to PQC. By adopting a layered quantum cyber-resiliency strategy and embedding PQC early into the design of CBDCs and tokenized asset platforms, countries can future-proof their financial infrastructures against quantum-enabled threats (Hupel and Rafiee 2024). Similarly, investment in shared quantum testbeds for financial modelling, payments and clearing systems could accelerate both learning and trust in practical applications.

Yet these opportunities exist against a backdrop of significant threats. International rivalry risks fragmenting global quantum standards and supply chains, undermining the interoperability that financial systems depend upon. Technical fragmentation, including competing PQC standards, diverging regulatory frameworks and selective export controls, could leave cross-border payment networks vulnerable. Systemic vulnerabilities are also evident in the global financial sector: delays in migration, inconsistent regulatory guidance and uneven adoption across jurisdictions create a landscape where attackers may exploit laggards (Swayne 2025a). In the most extreme case, a bifurcation of quantum-secure and quantum-vulnerable economies could emerge, leaving large segments of the global financial system exposed to instability and loss of trust.

The policy implication is clear: success in the quantum era will require not only technological breakthroughs but also strategic investment, coordinated governance and proactive international cooperation to align strengths, mitigate weaknesses, seize opportunities and guard against systemic threats.

Key Challenges

The transition from quantum research to secure, large-scale deployment in finance and other critical sectors is constrained by five key challenges detailed below. These interlinked challenges highlight that quantum readiness is not merely about research excellence but also about aligning governance, talent, supply chains, operational preparedness and global cooperation.

Governance fragmentation: Countries differ widely in their national quantum strategies.²⁰ While some link R&D, industry and security into integrated road maps, others lack regulatory coordination or PQC migration plans. This asymmetry hampers international cooperation and could compromise the resiliency of financial systems.

Workforce shortages: Even advanced economies face a scarcity of applied talent capable of bridging quantum science with financial applications. Skills in integrating PQC into information technology systems and modelling financial risk are especially limited, and smaller economies risk losing talent to global hubs amid a widening quantum divide, “where access to resources, infrastructure, knowledge and expertise is unevenly distributed, amplifying the current digital divide” (Open Quantum Institute 2025, 2).

Supply-chain vulnerability: Quantum hardware production (cryogenics, photonics and semiconductors) is concentrated in a handful of countries. Export controls and choke points slow adoption, raising costs and delaying secure deployment for central banks (Open Quantum Institute 2024).

Financial sector readiness: Awareness is growing but practical preparedness lags. Most institutions are still in pilot phases, with few concrete migration timelines. CBDCs, stablecoins and tokenized assets remain particularly exposed to quantum threats.

International standards race: Differing approaches by NIST, ETSI and ISO on the commercialization of quantum technologies risk fragmenting PQC and quantum communication standards. Divergent frameworks could undermine interoperability and increase compliance costs, though early movers may set global baselines. However, it is important to note that a variety of standards bodies are developing guidance and coordinating on quantum technologies and associated terminology, testing and evaluation methodologies, interoperability requirements and quantum-safe security measures (ITU 2021).

Quantum Scenarios

Scenario Analysis

Policy makers — including central banks and finance ministries — must prepare for an uncertain future, including preparing contingencies. Scenarios offer a valuable way to map out potential futures and can stimulate critical thinking and informed discussion.

This section explores four distinct, plausible scenarios relating to the evolution of quantum technologies (see Table 5). The scenarios span a broad spectrum of possibilities and are not intended to be viewed through either an inherently

²⁰ See the Quantum Technology Observatory for Policy and Society’s interactive tool (<https://qtobservatory.org/resources/national-strategies/>).

positive or negative lens. There are, of course many other possible scenarios, as there are many variables and uncertainties. It is important to stress that the scenarios are not mutually exclusive and may unfold concurrently as they are shaped by overlapping and compounding conditions.

Table 5: Four Quantum Scenarios

	1. Allied acceleration <i>research, standards, supply chains</i>	2. Slow diffusion <i>selective action</i>	3. Blocs <i>fragmentation</i>	4. Breakthrough <i>revolution</i>
Description	Significant cooperation among G7+ and OECD partners (and India) on PQC migration, standards testbeds and supply-chain resilience.	Modest cooperation among G7+ key allies makes progress on limited issues such as PQC migration.	Non-cooperative bloc dynamics between two or more different trade and technology blocs limits overall progress.	Major science and technology breakthroughs (e.g., a CRQC) yield step-change capability in one or more countries.
Key variables	Economies are broadly open in the sector. Interoperability across private sector and allied country systems is robust and cumulative. Openness, within limits, with other countries.	Economies are relatively open in the sector. Interoperability across private sector and allied country systems is robust. Openness is constrained with other countries.	Economies are quite open within allied groups but external outbound/inbound screening is high. Export controls deepen, and openness between blocs is very low.	Breakthrough would considerably raise the stakes for international cooperation, and could lead either to a more open or a more closed system.
Key outcomes	Adoption is steady and spread across allied hubs, and supply chains shift toward G7+. Research and investment help drive more significant technological advances across the sector. BRICS+ members remain competitive in rare earths and manufacturing, but their global standards influence declines.	Short-term focus and payoff on PQC but little else. Positive spillovers for the broader research sector are limited. BRICS+ members have greater opportunity to build technological advantage and influence evolution of global infrastructure and standards.	Adoption proceeds within blocs, creating inefficient supply chains. Incompatible standards constellations emerge. China controls some critical inputs (rare earths) and G7+ countries adopt ally-only procurement policies.	Could create winner-takes-most dynamics, including de facto standards for the rest of the world, and exacerbate economic/military power asymmetries. Controls tighten on IP and key components. Third countries pursue subsidy route to attempt to catch up. Highest quantum capabilities become essential for superpowers.

Source: Authors.

Note: BRICS+ is an intergovernmental organization comprising 10 countries — Brazil, Russia, India, China, South Africa, Egypt, Ethiopia, Indonesia, Iran and the United Arab Emirates (UAE).

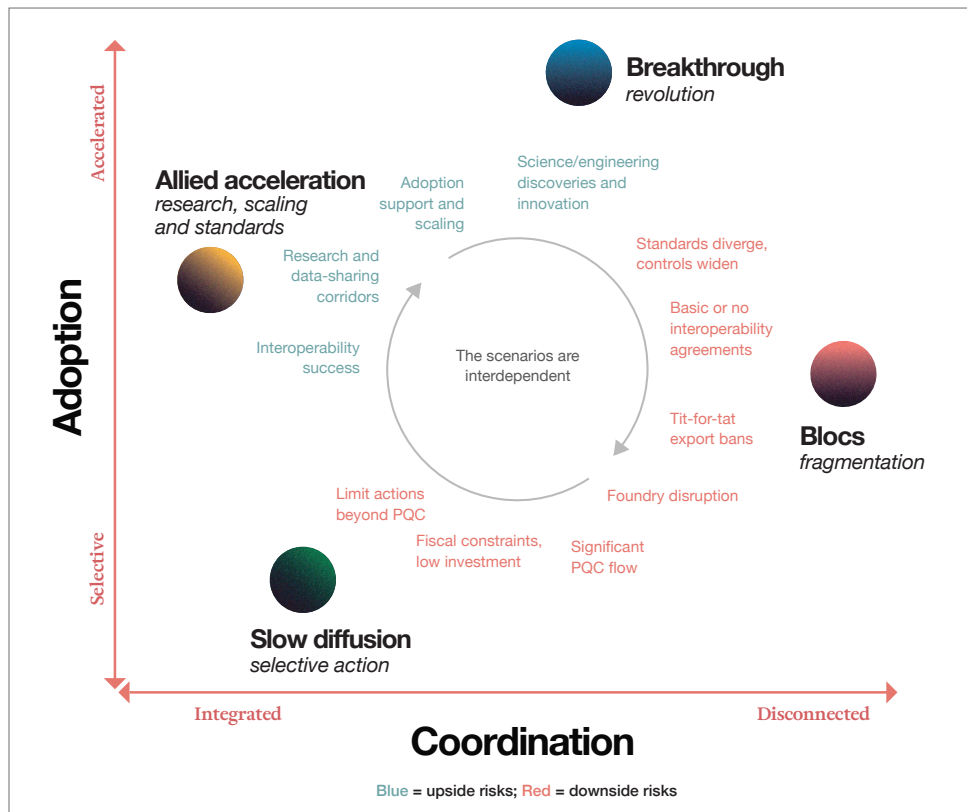
Scenario 1 (allied acceleration) assumes that there are increased and reasonably coordinated actions among a core set of partners centred around the G7. It also assumes that increased activity and cooperation will have positive effects among allies, which, while neither a necessary nor sufficient condition, could increase the likelihood of scenario 4 (breakthrough). Similarly, scenario 1 will not necessarily prevent scenario 3 (blocs), as the emergence of blocs — or not — will most likely be determined by broader geopolitical factors that determine the state of economic

and security partnering. Indeed, the emergence of broader economic and/or security blocs (as distinct from quantum dynamics) could create frameworks for greater allied cooperation on quantum technologies.

Scenario 2 (slow diffusion), with more limited allied coordination and positive spillovers, is probably closest to the current state of play in 2026. Once again, scenario 2 does not create a pathway for other scenarios, but it may influence them. Scenario 4 assumes a technological breakthrough, whereas all other scenarios could evolve from current technological conditions. Scenario 4 assumes that a key breakthrough is plausible (assumed here in the example to be achieving a CRQC, within a compressed timeframe). Some leading computer companies claim they are likely to achieve some form of CRQC within five years.²¹

There is no straightforward adoption path ahead under any scenario; movement toward one or another could meander. There could, of course, also be transitional periods between different outcomes, and it is a given that there will be negative stresses and positive catalytical events and unforeseen developments. Some potential stressors and catalysts are described in Figure 2 as upside and downside risks. The circular arrows in the middle represent multi-directional influences and dynamics.

Figure 2: Quantum Adoption and Coordination Risks



Source: Authors.

²¹ For example, IBM projects a large-scale, fault-tolerant quantum computer by 2029 (see Mandelbaum et al. 2025).

On the one hand, the allied acceleration scenario could maximize positive spillovers and build market depth and is likely the cheapest route to build overall resilience. At least some elements of a fragmentation scenario appear likely in the current system and may become features in parts of the quantum stack. A slow diffusion scenario could allow for some guardrails to be built. On the other hand, over-engineering standards or industrial policies could raise compliance costs and potentially reduce private sector-led investment and initiatives.

Key Takeaways for Policy Makers

Despite high levels of uncertainty and complexity in quantum technology evolution, there are a variety of options that G7 policy makers have at their disposal to mitigate risks and leverage opportunities presented by these rapidly evolving technologies. Indeed, central banks and finance ministries can play a unique role in shaping policy responses at both the national and global levels, as financial markets are a central arena for quantum technology development, deployment and governance innovation.

The trajectory of quantum adoption and its integration into financial and economic infrastructure will depend on whether governments, regulators and industry can translate awareness into coordinated, tangible actions. Based on the current readiness landscape, priority interventions can be structured across three tiers: national, international and public-private collaboration. This special report’s key recommendations are summarized in Table 6.

Table 6: Priority Actions for Consideration

National-Level Priorities	International-Level Priorities (G7+)	Public-Private Collaboration
<p>Accelerate adoption of quantum-resiliency plans that address awareness and critical capacity building, through planning, to executing cryptographic migration in critical financial systems (payments, securities, interbank).</p> <p>Include a basic quantum-related operational disruption scenario in economic and financial supervisory stress tests.</p>	<p>Establish a G7+ Quantum Financial Resilience Task Force, with classified access, to align quantum-safe migration timelines, standards, export controls and incident response.</p> <p>Advance multilateral standards and practices for quantum-safe finance and banking assets, including CBDCs/stablecoins.</p>	<p>Launch co-funded pilots in clearing, settlement and payment systems.</p>

National-Level Priorities	International-Level Priorities (G7+)	Public-Private Collaboration
<p>Integrate regulators into national quantum councils to align R&D, cybersecurity and supervision.</p>	<p>Develop shared central bank testbeds for payments, CBDCs/ stablecoins and risk modelling.</p>	<p>Implement regulatory sandboxes for testing post-quantum security solutions before scaling.</p> <p>Create secure knowledge-sharing platforms for quantum threat intelligence.</p>
<p>Build supply-chain resilience with incentives for domestic production, domestic industrial innovation and integration across the value chain.</p> <p>Assess vendor-concentration dashboards for gaps or vulnerabilities in quantum-relevant components/services.</p> <p>Expand talent pipelines through increased training capacity, fellowships, PPPs for budding researcher interchanges, and incentives to retain expertise (for example, encourage industry demand and capacity to engage in meaningful projects).</p>	<p>Coordinate on supply-chain resiliency.</p> <p>Participate in cross-border research collaboration and complementarity through community resources and R&D exchange programs to advance innovation and build talent.</p>	<p>Support the adoption of quantum-resiliency plans for entities across the finance and banking sectors.</p>

Source: Authors.

While technical details of breakthroughs in the quantum space are indeed uncertain, the costs of policy inaction are certain to be high. Through championing the policy efforts noted above, the G7 can take decisive action while remaining flexible and adaptive to changes in the technological environment, helping to ensure quantum technologies strengthen global stability and shared prosperity, while mitigating outcomes that deepen fragmentation and the global digital divide. A strong framework for ongoing regulatory discussion will help allied nations navigate foreseen and unforeseen challenges of quantum technological development.

Appendix 1

Table A1: Select Deployment Cases for Quantum in Finance

Technology Type	Case	Deployment Country	Corporation/Institution
Quantum computing	Quantum annealing used for portfolio optimization (Sakuler et al. 2023)	Austria	Raiffeisen Bank International
	Ping An Insurance collaborates with start-up to identify fraudulent behaviour using quantum computing (Tong 2023)	China	Ping An Insurance
	Huaxia Bank partners with SpinQ (2025) to develop quantum AI models for smarter commercial banking decisions		Huaxia Bank, SpinQ
	Bank of Canada uses quantum computing for payment systems (McMahon et al. 2022)	Canada	Bank of Canada
	Italian bank deploys quantum machine learning for fraud detection (World Quantum Summit 2025)	Italy	Intesa Sanpaolo
	BBVA (2024) trials distributed quantum simulation in the cloud	Spain	BBVA, VASS, AWS
	Quantum-inspired algorithms used in advanced exotic derivatives pricing (Terra Quantum 2025)		BBVA, Terra Quantum
	Quantum computing used in investment portfolio selection and bond portfolio optimization (D-Wave Quantum, n.d.)		D-Wave Quantum
	Turkish bank creates model to predict financial crashes (World Economic Forum 2025)	Turkey	Yapı Kred
	JP Morgan uses quantum deep hedging for derivative pricing (Smith-Goodson 2023)	United States	JPMorgan Chase, QC Ware
SandboxAQ (2025) optimizes multi-asset hedge fund strategy under extreme market scenarios	SandboxAQ		
Wells Fargo uses quantum computing for recalculation pricing (Apte 2022)	Wells Fargo, MIT-IBM Lab		

Technology Type	Case	Deployment Country	Corporation/Institution
Quantum communication	ExeQuantum deploys PQC in finance (see www.exequantum.com/use-cases#use-cases)	Australia	ExeQuantum
	ICBC (2017) transmits Beijing-Shanghai internet-banking remote data via quantum communication technology	China	ICBC
	People's Bank of China develops clearing and payment system (Qi 2023)		People's Bank of China
	Toshiba Europe uses QKD to transmit secure quantum data 254 km via German telecom network (Swayne 2025b)	Germany	Toshiba Europe
	Banque de France (2024) and Monetary Authority of Singapore conduct PQC experiment to enhance communication security	France, Singapore	Banque de France, Monetary Authority of Singapore
	Project Leap migrates global payment systems to quantum-safe cryptography (see www.bis.org/about/bisih/topics/cyber_security/leap.htm)	France, Germany, Italy	BIS, Banque de France, Deutsche Bundesbank, Bank of Italy, Nexi-Colt, SWIFT
	Intercontinental quantum-safe link established between three central banks (Interbank Convention for Automation 2024)	Italy, France, Canada	Banca d'Italia, Banque de France, Bank of Canada
	Japan conducts low-latency transmission of highly confidential data using quantum cryptography for large-volume financial transaction data (NICT 2022)	Japan	Nomura HD, Nomura Securities, NICT, NEC
	NTT Data invests in quantum-resistant encryption project (Quanta Intelligence 2024)		NTT Data
	Ueno Bank deploys quantum-resistant cryptography to secure signatures and blockchain (Swayne 2025c)	Paraguay	Ueno Bank, SignQuantum, QANplatform
	Russian bank deploys quantum-safe blockchain platform (Riley 2017)	Russia	Gazprombank, Russian Quantum Center
JPMorgan Chase implements quantum-secured network connecting two Singapore data centres (Baker 2024)	Singapore	JPMorgan Chase	
Banco Sabadell adopts PQC (Accenture 2024)	Spain	Banco Sabadell, Accenture, QuSecure	

Technology Type	Case	Deployment Country	Corporation/Institution
	Project Tourbillon implements quantum-safe blind signatures (BIS 2023)		Swiss National Bank, BIS
	QKD system secures communications link between bank headquarters and disaster recovery centre (ID Quantique 2017)	Switzerland	ID Quantique
	Quantum vault protects digital asset storage (ID Quantique 2020)		ID Quantique
	QSafe launches quantum-secure, multichain crypto wallet (see www.qsafewallet.com/)	Singapore, Switzerland, UAE	Quranium
	Santander (2024) develops PQC project		Santander, National Cybersecurity Center of Excellence, GitHub, Microsoft
	QKD-encrypted connection established between Wall Street's financial markets and a data centre in New Jersey (Quantum Xchange 2019)	United States	Quantum Xchange, Toshiba
	Mastercard launches QKD systems for cybersecurity threat (Apte 2023)		Mastercard
	QRNG used in monthly prize draws for UK Premium Bonds (ID Quantique 2019)		ID Quantique
	HSBC (2023a) joins the United Kingdom's pioneering commercial quantum-secure metro network	United Kingdom	HSBC, AWS, BT
	HSBC (2024) combines PQC and QRNG to secure tokenized gold transactions		HSBC, Quantinuum
	JPMorgan Chase, Toshiba and Ciena build first QKD network to secure mission-critical blockchain application (Pistoia and Shetty, n.d.)	Unspecified*	JPMorgan Chase, Toshiba, Ciena
	JP Morgan's QKD readiness for the transition toward quantum-safe methodologies (Ainger 2023)	Unspecified**	JPMorgan Chase

Source: Authors.

Notes: This table presents select cases for which information is readily available in the public domain. Cases include quantum computing and communication. In exploring quantum sensing, the authors found no publicly disclosed cases of deployment in the financial sector, although quantum-timing technologies such as atomic clocks are referenced for their potential relevance to financial transactions. See "Case Study 4: Ultra-precise timestamps for financial transactions" in World Economic Forum (2025,12) and Xairos (www.xairos.com/about). Deployment cases are defined broadly to include tests, pilots, trials and demonstrations of quantum technologies conducted in real-world or production-like environments. Purely theoretical studies, simulations or lab-only proofs of concept are excluded.

* Deployment country not specified; case conducted in JPMorgan Chase's fibre-optic simulation lab, a production-like environment using real optical networking hardware and blockchain traffic.

** Deployment country not specified; announcement made with no indication of geographic location.

Appendix 2

As quantum capabilities develop, it is essential to build an accurate understanding of the global quantum landscape to inform situational awareness, strategic planning and cooperative governance. However, this landscape is not uniform. Indeed, countries have varying priorities and approaches, reflecting wide variations across R&D activity, industrial capacity, regulatory responsiveness and workforce readiness.

This analysis aims to map this landscape, evaluating countries across the G7, along with emerging and influential players, to provide a strategic baseline for:

- identifying national strengths and vulnerabilities;
- supporting targeted investment and international collaboration; and
- informing financial governance strategies in an age of quantum disruption.

Importantly, this assessment is not intended to rank countries but rather to highlight areas of comparative advantage across the four conduits and their key variables. By identifying where individual nations excel — and where they face constraints — the analysis can help policy makers pinpoint opportunities for complementary collaboration, leveraging one country's strengths to address another's gaps and fostering a more coherent, resilient global quantum ecosystem.

The QIRHM

To achieve this aim and help policy makers, central banks and industry leaders understand how prepared countries are to lead in the quantum age, the authors developed a simple and practical tool: the QIRHM.

The QIRHM is organized around four core transmission conduits²² that enable quantum technologies to transition from lab-scale experiments to systemic enablers in finance and security (see Table 3). These conduits achieve two key purposes: as a strategic lens for governments and central banks to evaluate their own nation's position, and as a comparative tool for situational awareness across the G7 and other strategically relevant economies.

Heat Map Methodology

The QIRHM assigns each country a colour that reflects its performance across the four core transmission conduits and their key variables. Countries included in the analysis are evaluated not just on individual pillars but also on their conduit coherence (that is, the degree to which strengths across research, application, governance and talent are mutually reinforcing).

The authors began by gathering publicly available data from well-known international indices and reports, including metrics such as the number of quantum research papers a country produces, whether it has a national quantum strategy and whether it is part of international rulemaking groups. The authors

²² Each conduit is evaluated using a hybrid framework that combines quantitative indicators (for example, publications, patents, VC, workforce size) with qualitative assessments of national strategies, public-private ecosystems and policy alignment.

also looked at the start-up ecosystem, whether countries are running pilot projects and how they are developing talent.

Then, the authors translated all that information into simple scores from red, to yellow, to green:

- **Red** means emerging or developing capacity.
- **Yellow** means moderate capacity.
- **Green** means strong capacity.

Where official data was missing, the authors used reputable sources such as policy documents, expert commentary and international news to make a reasonable judgment. The heat map also underwent a formal peer review completed by multiple international quantum experts and leaders to ensure rigour and accuracy.

Which Countries Were Assessed?

The authors looked at 13 countries (listed below) that are either global leaders or emerging players in quantum technology, chosen because they play a significant role in shaping global finance, security and digital policy.

- **G7 countries:** Canada, France, Germany, Italy, Japan, the United Kingdom and the United States.
- **Select OECD countries:** Australia, the Netherlands and South Korea.
- **Other economies:** China, India and Russia.

What Does the QIRHM Tell Us?

The QIRHM gives us two key outputs:

- **A visual scorecard (heat map):** This shows how each country is doing across the four conduits.
- **Country profiles:** For each country, the authors explain where it stands out, where it lags and where it should focus next.

Why This Matters

Quantum technologies could reshape everything from how banks secure transactions to how we forecast economic risks. But not every country is equally prepared. The QIRHM helps:

- **central banks** plan for secure digital finance;
- **governments** identify gaps in investment or workforce; and
- **allies and partners** coordinate on global rules and cooperation.

It turns complex science into clear, actionable insights for decision makers who are shaping the future of digital and economic infrastructure (see Table A2).

Table A2: The QIRHM for the 13 Countries in the Analysis

Country	A1 R&D	A2 Nat. Labs	A3 Pubs/Cites	B1 Start-ups	B2 Finance Pilots	B3 Supply Chain	B4 Industrial Strategy	B5 Patents/VC	C1 Nat. Strategy	C2 Export Controls	C3 Standards	C4 PQC Readiness	C5 Reg. Coord.	D1 Professionals	D2 Education	D3 Student Retention	D4 Talent Demand
Canada	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
France	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Germany	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Italy	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Japan	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
UK	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
US	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
S. Korea	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Netherlands	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Australia	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
China	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
India	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Russia	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Source: Authors.

Analysis of the Variable-Level Qualitative Heat Map

The qualitative heat map reveals a diverse landscape of quantum readiness, with clear clusters of global leaders, industrial powerhouses and emerging participants. While some countries demonstrate consistent strength across all conduits, others show concentrated excellence in specific domains.

Global Leaders: Consistency Across All Variables

The United States and the United Kingdom stand out for their across-the-board strengths:

- **United States:** Dominates in applications and industrial integration (B1–B5 conduits) through a robust start-up ecosystem, deep VC flows, mature supply-chain participation and multiple financial sector pilots. It also holds top-tier positions in research (A1–A3), yet recent changes to immigration policy risk talent absorption and retention (D1–D4).
- **United Kingdom:** Excels in technological and research capabilities (A1–A3) and governance and regulation (C1–C5), with high-quality research output, significant public investment and leadership in international quantum standards. The United Kingdom's industrial integration is also strong, though less capital-intensive than the United States. Yet post-Brexit changes to immigration policy impact its ability to attract and retain talent (D3–D4).

Industrial Powerhouses: Strong in Applications and Governance

- **China:** Matches its research capabilities with a rapid scaling of applications (B1–B5) and strong governance frameworks (C1–C5). It leads in supply-chain integration, hardware manufacturing, state-led industrial strategy and research publication quality (A3).
- **Germany:** Demonstrates deep research excellence (A1–A3) and robust governance structures. It has a notable role in quantum supply chains and industrial strategy, though its start-up ecosystem and private funding levels are less dynamic than the United States/China.
- **Japan:** Combines strong research capacity (A1–A3) with an emphasis on secure communications and cryptographic resilience. Its industrial integration is supported by major firms such as NEC, Fujitsu and Toshiba, which lead in quantum sensing and communication pilots. Governance frameworks are well developed, with Japan's Science, Technology, and Innovation Basic Plan embedding quantum into broader national security and industrial strategies (C1–C5) (Council for Science, Technology and Innovation 2021). However, VC activity and start-up density remain modest compared to the United States and China, limiting the pace of commercialization despite strong state and corporate leadership.

Balanced Performers with Strategic Gaps

- **France** and **Australia** possess strong research and talent pipelines (A and D conduits), with France also competitive in industrial applications. Both countries, however, show moderate governance readiness and limited scale in financial sector pilots.
- **Canada** shows a similar profile, with strong research (A1–A3) and talent (D1–D4), plus emerging governance capacity. Its industrial integration is moderate, reflecting a smaller start-up base and partial supply-chain participation.

Fast-Rising Economies

- **India** exhibits strong momentum in start-ups and private funding, catapulted and initiated by the public sector through its National Quantum Mission (B1, B5), and a modest research publication intensity (A3) compared to its size. However, gaps remain in governance execution (C1–C5) and talent development (D1–D4), both of which are essential to convert potential into sustained leadership.

Selective Strengths and Niche Players

- **South Korea** benefits from robust governance proxies (C1, C3, C5) and emerging supply-chain capabilities but lacks depth in research output and start-up activity.
- **The Netherlands** has niche strengths in supply-chain participation (B3) and research publication quality (A3) but moderate-to-emerging capacity across other variables.

Emerging or Fragmented Readiness

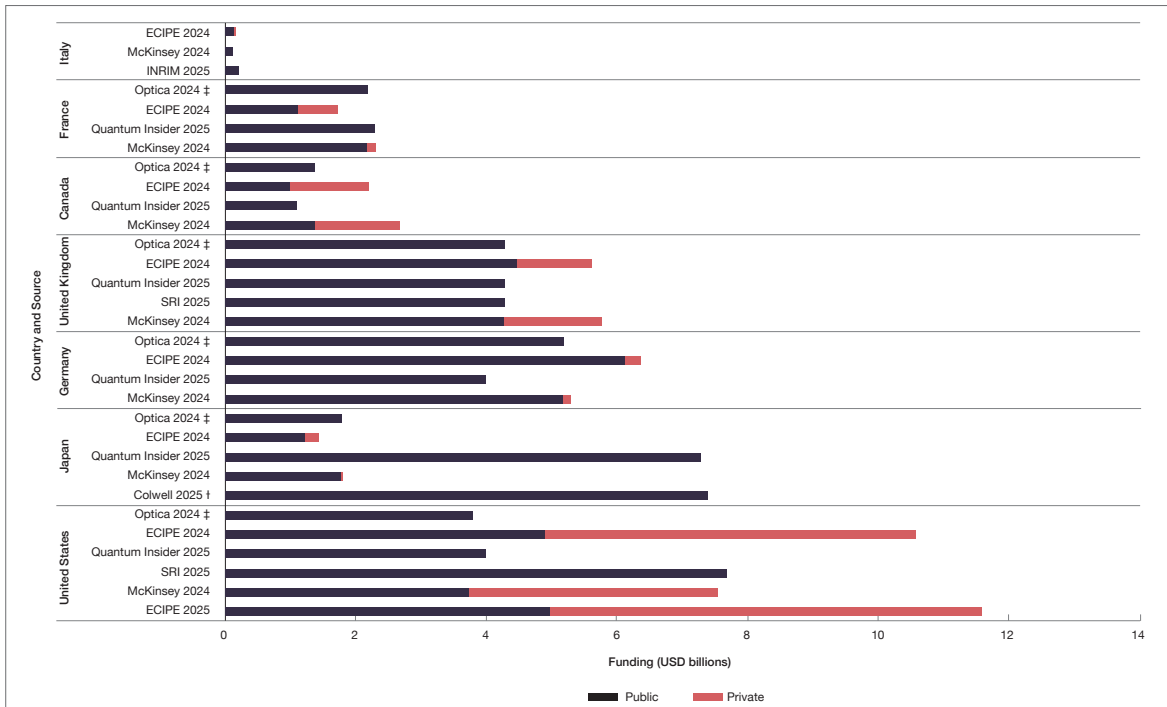
- **Italy** and **Russia** are in the early stages of quantum ecosystem development, with pockets of strength in publication quality (A3) but limited activity in applications, governance and talent.

Strategic Insights

- **Leadership correlates with balance:** The top performers sustain capacity across all conduits, not just one.
- **Industrial scaling is decisive:** Countries with strong research but weak application pipelines risk falling behind.
- **Governance maturity is uneven:** Even advanced economies show gaps in PQC readiness and cross-sector regulatory coordination.
- **Talent bottlenecks persist globally:** While the United States, the United Kingdom and a handful of other countries have mature pipelines, most face skill shortages that could limit commercialization.

Appendix 3

Figure A3.1: Public vs. Private Funding in Quantum Technologies by G7 Countries



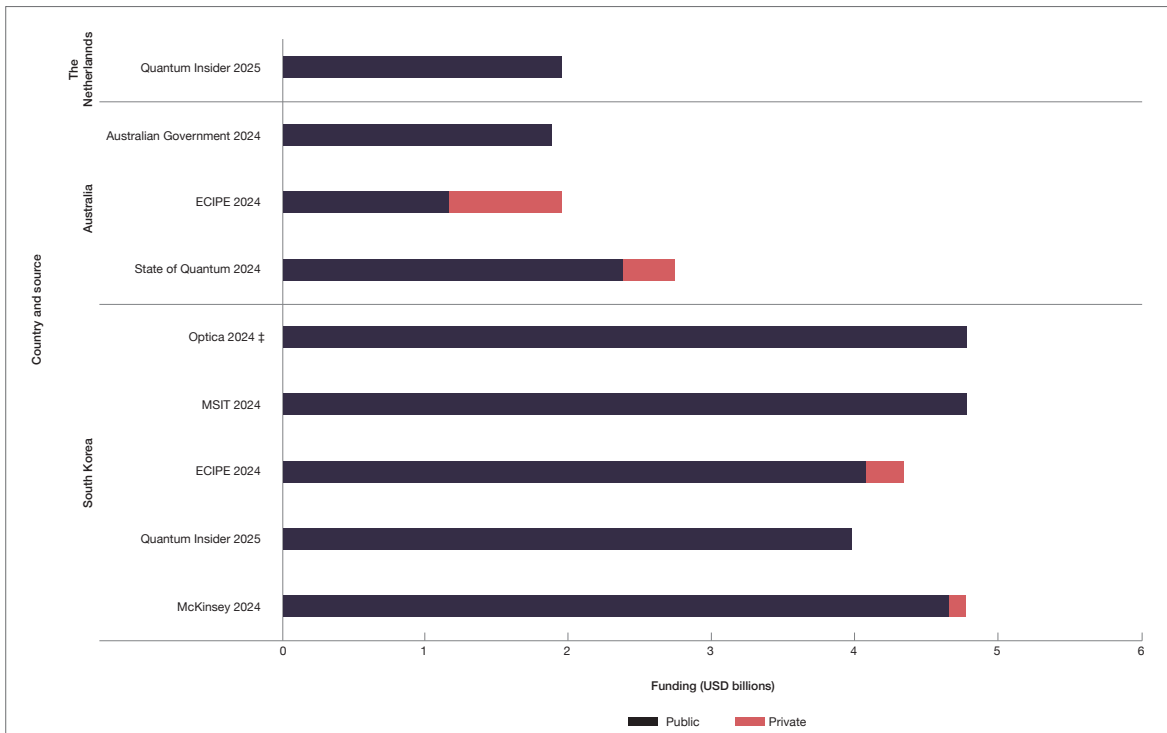
Source: Authors.

Notes: Numbers included capture all publicly disclosed funding spent and announced up until the data's publication.

† denotes planned funding through 2035.

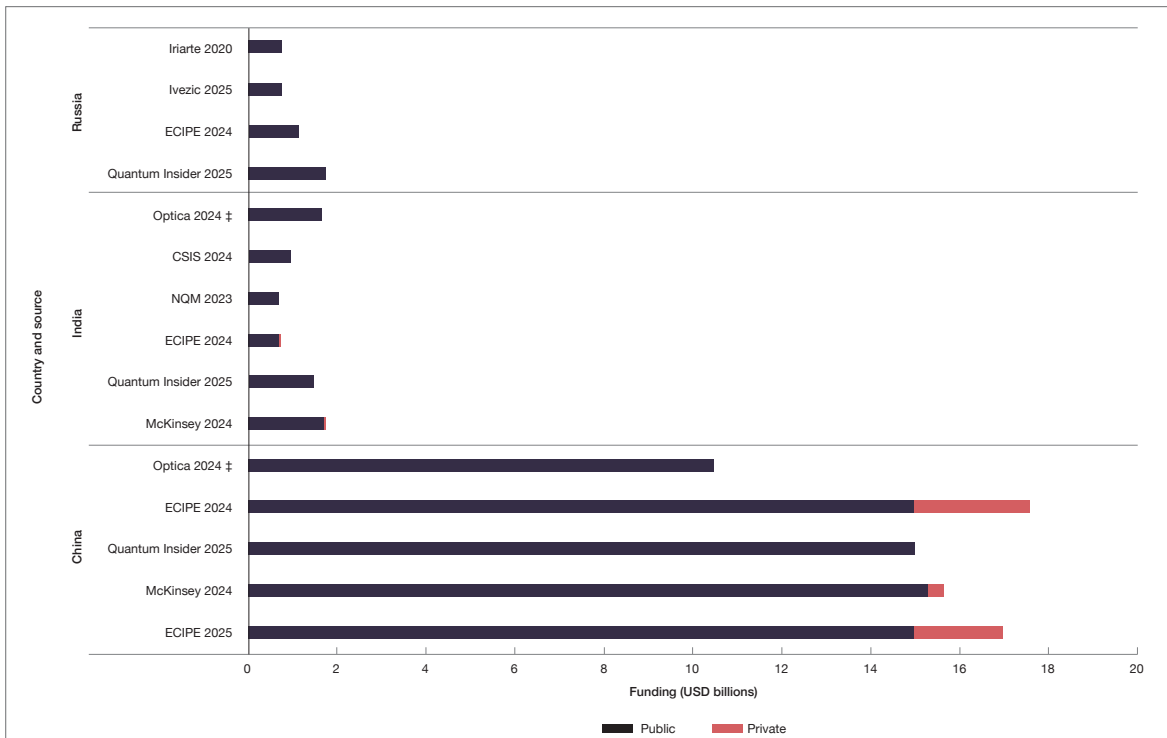
‡ draws heavily from McKinsey's 2024 *Quantum Technology Monitor*.

Figure A3.2: Public vs. Private Funding in Quantum Technologies by Select OECD Countries



Source: Authors.

Figure A3.3: Public vs. Private Funding in Quantum Technologies by Select Economies



Source: Authors.

Appendix 4

Table A4: Quantum Indices

Index	Type	Core Metrics	Countries Covered
MIT Quantum Index (Ruane et al. 2025)	Quantitative	Papers, H-index, patents, funding, researchers, testbeds, public opinion	United States, China, European Union, United Kingdom, Germany
Australian Strategic Policy Institute Tracker (Gaida et al. 2023)	Quantitative	Papers (top 10 percent), patents, H-index	United States, China, India, Australia
European Patent Office (2023) Monitor	Quantitative	Patents (domestic, families)	United States, China, Japan, Germany, France
QED-C (2025) Industry Report	Quantitative	Market size, investment, patents, workforce	United States, European Union, China
RAND (Parker et al. 2022)	Qualitative	Funding, companies, policy	United States, China
Quantum Insider (Dargan 2026)	Qualitative	Funding, initiatives	G7 + China, India, Australia
QURECA (2025)	Qualitative	Funding, projects	G7 + others
McKinsey & Company (2025)	Qualitative	Investment, market trends	United States, China, European Union
RAND (Parker et al. 2023)	Mixed	Industrial base mapping, supply chain, allied capacity	United States, EU allies, Australia, Canada, Japan
CSIS ChinaPower (Hart et al. 2024)	Qualitative	National capacity, government/industry initiatives, strategic implications	China (with comparisons to United States and peers)
Information Technology and Innovation Foundation (Omaar and Makaryan 2024)	Quantitative	Patents, publications, commercialization indicators	China versus US and OECD benchmarks
Canadian Institute for Advanced Research (Kung and Fancy 2021)	Qualitative	National strategies, government initiatives, policy environment	Canada, United States, European Union, China (and others)

Index	Type	Core Metrics	Countries Covered
Mercator Institute for China Studies (Hmaidid and Gorenweg-Lau 2024)	Mixed	Leadership by domain (communications, computing, sensing), government strategy, innovation type	United States, China; also Germany, Switzerland
U.S.-China Economic and Security Review Commission (2024)	Qualitative	Military significance, industrial policy, innovation diffusion	United States, China
Harvard Kennedy School Belfer Center for Science and International Affairs (Rosenbach et al. 2024)	Mixed	Quantitative and narrative ranking across quantum technology	G7 + others
Special Competitive Studies Project (2025)	Mixed	Gap analysis across frameworks, trust, coordination	United States and allies
Global Innovation Index 2024 (World Intellectual Property Organization 2024)	Quantitative	Innovation ecosystem, IP, R&D spending	130+ countries (global)
Lowy Institute Asia Power Index (Patton, Sato and Lemahieu 2024)	Quantitative	Science/technology power, defence technology	Indo-Pacific countries

Appendix 5

Table A5: SWOT Sources

Pillar	Sources
1. Technological and research capabilities	Council of Canadian Academies (2023)
	Erixon et al. (2025)
	European Patent Office (2023)
	Gaida et al. (2023)
	Geneva Science and Diplomacy Anticipator (see https://radar.gesda.global/topics/quantum-computing)
	Omaar and Makaryan (2024)
	McKinsey & Company (2025) <i>Quantum Technology Monitor</i>
	National Quantum Computing Centre (see www.nqcc.ac.uk/technology-and-research/)
	Ernst & Young (2022)
	OECD (2025a)
	Parker et al. (2023)
	Patton, Sato and Lemahieu (2024)
	QED-C (2025)
	Rosenbach et al. (2025)
	Ruane et al. (2025)
2. Applications and industrial integration	Acharya et al. (2025)
	Albareti et al. (2022)
	Auer et al. (2024)
	Evident (2025)
	Dalzell et al. (2025)
	Deshpande, Das and Mueller (2025)
	European Quantum Communication Infrastructure (see https://prism-euroqci.eu/euroqci)
	Fernández-Villaverde and Hull (2023)
	Ghysels, Morgan and Mohammadbagherpoor (2025)
	Gilboa, Jain and McClean (2025)
	Herman et al. (2022)
	Khan, et al. (2025)

Pillar	Sources
	Mans (2025)
	Markov, Rastunkov and Adame (2024)
	Marsden et al. (2025)
	Martini et al. (2025)
	Marin (2024)
	McKinsey & Company (2024, 2025)
	McMahon et al. (2022)
	Parker et al. (2023)
	Priazhkina et al. (2024)
	Quantum Ecosystems Technology Council of India (2023)
	Randazzese et al. (2023)
	<i>The Moscow Times</i> (2023)
	Interbank Convention for Automation (2024)
	Vu, Cheng and Rebentrost (2025)
3. Governance and regulation	So-young (2025)
	Auer et al. (2025)
	Government of Canada (2025)
	Canadian Centre for Cyber Security (2025)
	Davis, Aboy and Minssen (2025)
	Department for Science, Innovation and Technology (2023)
	Department of Defence (see www.defence.gov.au/business-industry/exporting/export-controls-framework)
	Department of Industry, Science and Resources (2023)
	Department of Science & Technology (2023)
	Federal Ministry of Education and Research (2023)
	Gruppo di lavoro per la strategia quantistica italiana (2025)
	Innovation, Science and Economic Development Canada (2022)
	Institute of Commercial Cryptography Standards (2025)
	Kung and Fancy (2021)
	Ministry of Science and ICT (2023a, 2023b)
	Center for Security and Emerging Technology (2015)
	Quantum Delta NL (2019)
	Netherlands, <i>Regeling aanvullende controlemaatregelen op de Verordening producten voor tweeterlei gebruik</i> , No 33838 (2024), online: https://zoek.officielebekendmakingen.nl/stcrt-2024-33838.html .

Pillar	Sources
	<p>EC, <i>Regulation (EU) 2022/2554 of the European Parliament and of the Council of 14 December 2022 on digital operational resilience for the financial sector and amending Regulations (EC) No 1060/2009, (EU) No 648/2012, (EU) No 600/2014, (EU) No 909/2014 and (EU) 2016/1011</i>, [2022] OJ, L 333, online: <www.eiopa.europa.eu/digital-operational-resilience-act-dora_en>.</p>
	<p>Gouvernement de France (2023)</p>
	<p>Secretariat of Science, Technology and Innovation Policy (2023)</p>
	<p>US, Bill HR 6227, <i>National Quantum Initiative Act</i>, 115th Cong, 2018 (enacted), online: <www.congress.gov/bill/115th-congress/house-bill/6227/text>.</p>
	<p>Australian Signals Directorate (2023)</p>
	<p>Indian Computer Emergency Response Team (2025)</p>
	<p>Center for Security and Emerging Technology (2021)</p>
	<p>Министерство цифрового развития, связи и массовых коммуникаций Российской Федерации (31 July 2020), Паспорт дорожной карты развития высокотехнологичного направления «Квантовые вычисления» на период до 2024 года [Passport of the road map for the development of the high-technology area “Quantum Computing” for the period up to 2024], Российская Федерация, online: <www.consultant.ru/document/cons_doc_LAW_384559/>.</p>
4. Talent and workforce	<p>European Quantum Industry Consortium (www.euroquic.org/members-list/)</p>
	<p>Gorney, Muñoz and Sherson (2025)</p>
	<p>Kaur and Venegas-Gomez (2022)</p>
	<p>Q-STAR (see https://qstar.jp/en/memberlist)</p>
	<p>Quantum Industry Canada (see www.quantumindustrycanada.ca/our-community/)</p>
	<p>QED-C (2025)</p>

Works Cited

- Accenture. 2024. "Banco Sabadell Collaborates with Accenture and QuSecure to Advance Quantum Safe Infrastructure." News release, December 16. <https://newsroom.accenture.com/news/2024/banco-sabadell-collaborates-with-accenture-and-qusecure-to-advance-quantum-safe-infrastructure>.
- Acharya, Atithi, Romina Yalovetzky, Pierre Minssen, Shouvanik Chakrabarti, Ruslan Shayduln, Rudy Raymond, Yue Sun et al. 2025. "Decomposition pipeline for large-scale portfolio optimization with applications to near-term quantum computing." *Physical Review Research* 7: 023142. <https://doi.org/10.1103/PhysRevResearch.7.023142>.
- Ainger, Neil. 2023. "Show report: Sibos23 — AI dominates FI priorities, but quantum is real tech revolution." LinkedIn, October 11. www.linkedin.com/pulse/show-report-sibos23-ai-dominates-fi-priorities-quantum-neil-ainger.
- Albareti, Franco D., Thomas Ankenbrand, Denis Bieri, Esther Hänggi, Damian Lötscher, Stefan Stettler and Marcel Schöngens. 2022. "A Structured Survey of Quantum Computing for the Financial Industry." Preprint, arXiv, April 21. <https://doi.org/10.48550/arXiv.2204.10026>.
- Alexeev, Yuri, Marwa H. Farag, Taylor L. Patti, Mark E. Wolf, Natalia Ares, Alán Aspuru-Guzik, Simon C. Benjamin et al. 2024. "Artificial Intelligence for Quantum Computing." Preprint, arXiv, November 14. <https://doi.org/10.48550/arXiv.2411.09131>.
- Apte, Poornima. 2022. "Wells Fargo prepares to take a quantum leap." CIO, June 17. www.cio.com/article/400745/wells-fargo-prepares-to-take-a-quantum-leap.html.
- — —. 2023. "Mastercard preps for the post-quantum cybersecurity threat." CIO, September 22. www.cio.com/article/652972/mastercard-preps-for-the-post-quantum-cybersecurity-threat.html.
- Arora, Rakesh, Han Du, Raza Ali Kazmi and Duc-Phong Le. 2025. "Privacy-Enhancing Technologies for CBDC Solutions." Staff Discussion Paper 2025-1. January 8. Ottawa, ON: Bank of Canada. <https://doi.org/10.34989/sdp-2025-1>.
- Auer, Raphael, Donna Dodson, Angela Dupont, Maryam Haghighi, Nicolas Margaine, Danica Marsden, Sarah McCarthy and Andras Valko. 2025. "Quantum-readiness for the financial system: a roadmap." BIS Paper No. 158. July. Basel, Switzerland: BIS. www.bis.org/publ/bppdf/bispap158.pdf.
- Auer, Raphael, Angela Dupont, Leonardo Gambacorta, Joon Suk Park, Koji Takahashi and Andras Valko. 2024. "Quantum computing and the financial system: opportunities and risks." BIS Papers No. 149. October. Basel, Switzerland: BIS. www.bis.org/publ/bppdf/bispap149.htm.
- Australian Signals Directorate. 2023. "Planning for Post-Quantum Cryptography." August. www.cyber.gov.au/sites/default/files/2023-08/PROTECT%20-%20Planning%20for%20Post-Quantum%20Cryptography%20%28August%202023%29.pdf.
- Baker, Berenice. 2024. "JPMorgan Chase Implements Quantum-Secured Network." IOT World Today, May 10. www.iotworldtoday.com/quantum/jpmorgan-chase-implements-quantum-secured-network.

- Banque de France. 2024. “Banque de France and Monetary Authority of Singapore conduct groundbreaking Post-quantum Cryptography experiment to enhance communication security.” Press release, November 5. www.banque-france.fr/en/press-release/banque-de-france-and-monetary-authority-singapore-conduct-groundbreaking-post-quantum-cryptography.
- BBVA. 2024. “BBVA runs successful trial of distributed quantum simulation in the cloud.” May 10. www.bbva.com/en/innovation/bbva-runs-successful-trial-of-distributed-quantum-simulation-in-the-cloud/.
- Bheemaiah, Kary and Connie Kuang. 2025. “8 technologies, ‘3Cs’ and one new innovation paradigm: How converging tech is redefining value chains.” World Economic Forum, June 3. www.weforum.org/stories/2025/06/technologies-converging-to-create-new-opportunities-for-business/.
- BIS. 2020. *Central bank digital currencies: foundational principles and core features*. BIS Report No. 1. Basel, Switzerland: BIS. www.bis.org/publ/othp33.pdf.
- — —. 2024. “Central bank digital currencies: System design.” November. Basel, Switzerland: BIS. www.bis.org/publ/othp88_system_design.pdf.
- — —. 2023. “Project Tourbillon demonstrates cash-like anonymity for retail CBDC.” November 29. www.bis.org/about/bisih/topics/cbdc/tourbillon.htm.
- Bobier, Jean-François, Matt Langione, Cassia Naudet-Baulieu, Zheng Cui and Eitoku Watanabe. 2024. “The Long-Term Forecast for Quantum Computing Still Looks Bright.” BCG, July 18. www.bcg.com/publications/2024/long-term-forecast-for-quantum-computing-still-looks-bright.
- Bogobowicz, Michael, Scarlett Gao, Mateusz Masiowski, Niko Mohr, Henning Soller, Rodney Zimmel and Matija Zesko. 2023. *Record Investments in Quantum Technology*. McKinsey & Company. www.mckinsey.com/capabilities/mckinsey-digital/our-insights/quantum-technology-sees-record-investments-progress-on-talent-gap.
- Brooke-Holland, Louisa. 2024. “AUKUS pillar 2: Advanced military capabilities.” September 2. Research Briefing No. 9842. London, UK: House of Commons Library. <https://researchbriefings.files.parliament.uk/documents/CBP-9842/CBP-9842.pdf>.
- Canadian Centre for Cyber Security. 2025. “Roadmap for the migration to post-quantum cryptography for the Government of Canada (ITSM.40.001).” June 23. Ottawa, ON: Canadian Centre for Cyber Security. www.cyber.gc.ca/sites/default/files/itsm.40.001-migration-post-quantum-cryptography-government-canada-e.pdf.
- Center for Security and Emerging Technology. 2021. “Outline of the People’s Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035.” Translation. May 13. <https://cset.georgetown.edu/publication/china-14th-five-year-plan/>.
- — —. 2022. “Notice of the State Council on the Publication of ‘Made in China 2025.’” Translation. March 10. <https://cset.georgetown.edu/publication/notice-of-the-state-council-on-the-publication-of-made-in-china-2025/>.
- Charbonneau, Martin and Michele Mosca. n.d. “Beyond survival: building cyber-resilient financial institutions in the quantum age.” *FinanceDay*. https://financeday.co.uk/beyond-survival-building-cyber-resilient-financial-institutions-in-the-quantum-age/#google_vignette.

- Council for Science, Technology and Innovation. 2021. *Science, Technology, and Innovation Basic Plan*. March 26. Tokyo, Japan: Government of Japan. www8.cao.go.jp/cstp/english/sti_basic_plan.pdf.
- Council of Canadian Academies. 2023. *Quantum Potential*. Expert Panel on the Responsible Adoption of Quantum Technologies. Ottawa, ON: Council of Canadian Academies. <https://cca-reports.ca/reports/quantum-technologies/>.
- D-Wave Quantum. n.d. “Quantum in Optimization: Real-World Customer Success Stories.” www.dwavequantum.com/media/wcvp0v0d/2024-10-quantum-in-optimization-real-world-customer-success-stories.pdf.
- Dalzell, Alexander M., Sam McArdle, Mario Berta, Przemyslaw Bienias, Chi-Fang Chen, András Gilyén, Connor T. Hann et al. 2025. *Quantum Algorithms: A Survey of Applications and End-to-End Complexities*. Cambridge, UK: Cambridge University Press. <https://doi.org/10.1017/9781009639651>.
- Dargan, James. 2026. “15 Leading Quantum Computing Countries With National Initiatives.” *Quantum Insider*, February 26. <https://thequantuminsider.com/2021/04/29/leading-quantum-computing-countries/>.
- Das, Subham, Ashtakala Meghanath, Bikash K. Behera, Shahid Mumtaz, Saif Al-Kuwari and Ahmed Farouk. 2025. “QFDNN: A Resource-Efficient Variational Quantum Feature Deep Neural Networks for Fraud Detection and Loan Prediction.” Preprint, arXiv, April 28. <https://doi.org/10.48550/arXiv.2504.19632>.
- Davis, Peter Alexander Earls, Mateo Aboy and Timo Minssen. 2025. “Regulatory Challenges and Opportunities of Export Controls on Quantum Computing.” Preprint, SSRN, October 7. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5404548.
- Department for Science, Innovation & Technology. 2023. *National Quantum Strategy*. March. London, UK: Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/6411a602e90e0776996a4ade/national_quantum_strategy.pdf.
- Department for Science, Innovation & Technology and Regulatory Horizons Council. 2024. “Regulating quantum technology applications: government response to the RHC.” Policy Paper, October 8. www.gov.uk/government/publications/regulating-quantum-technology-applications-government-response-to-recommendations-made-by-the-regulatory-horizons-council.
- Department of Industry, Science and Resources. 2023. *National Quantum Strategy*. May 3. Canberra, Australia: Australian Government. www.industry.gov.au/publications/national-quantum-strategy.
- Department of Science & Technology. 2023. “National Quantum Mission.” April 19. New Delhi, India: Government of India. <https://dst.gov.in/national-quantum-mission-nqm>.
- Deshpande, Sangram, Elin Ranjan Das and Frank Mueller. 2025. “Currency Arbitrage Optimization using Quantum Annealing, QAOA and Constraint Mapping.” Preprint, arXiv, February 8. <https://arxiv.org/abs/2502.15742>.
- Digital Agency. 2025. “Third Meeting of the Japan-EU Digital Partnership Council Held.” May 15. www.digital.go.jp/en/news/9b948ac0-10fb-47d0-aff8-7534d9bb042b.

- DuBose, Rich and Mohan Madhupathy Rao. 2025. "Harvest now, decrypt later: Why today's encrypted data isn't safe forever." *The Stack* (blog), May 21. www.hashicorp.com/en/blog/harvest-now-decrypt-later-why-today-s-encrypted-data-isn-t-safe-forever.
- Erixon, Fredrik, Andrea Dugo, Dyuti Pandya and Oscar du Roy. 2025. "Benchmarking Quantum Technology Performance: Governments, Industry, Academia and their Role in Shaping our Technological Future." Policy Brief No. 06/2025. June. European Centre for International Political Economy. https://ecipe.org/wp-content/uploads/2025/03/ECI_25_PolicyBrief_06-2025_LY03.pdf.
- Ernst & Young. 2022. "How can you prepare now for the quantum computing future?" EY Quantum Readiness Survey 2022. June. www.ey.com/content/dam/ey-unified-site/ey-com/en-uk/insights/emerging-technologies/documents/ey-quantum-readiness-survey-2022.pdf.
- European Patent Office. 2023. *Quantum computing*. Insight Report. January. Munich, Germany: European Patent Office. https://link.epo.org/web/epo_patent_insight_report-quantum_computing_en.pdf.
- Evident. 2025. "Banks' Quantum Solace." Banking Brief. March 20. <https://evidentinsights.com/bankingbrief/banks-bet-on-quantum-computing/>.
- Federal Ministry of Education and Research. 2023. *Quantum Technologies Conceptual Framework Programme of the Federal Government*. April. Bonn, Germany: Federal Ministry of Education and Research. www.quantentechnologien.de/fileadmin/public/Redaktion/Dokumente/PDF/Publikationen/Quantum-Technologies-Conceptual-Framework-2023_english_bf_C1.pdf.
- Fernández-Villaverde, Jesús and Isaiah Hull. 2023. "Dynamic Programming in Economics on a Quantum Annealer." NBER Working Paper No. w31326. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4475924.
- French Cybersecurity Agency, Federal Office for Information Security, Netherlands National Communications Security Agency and Swedish National Communications Security Authority. 2024. "Position Paper on Quantum Key Distribution." https://cyber.gouv.fr/sites/default/files/document/Quantum_Key_Distribution_Position_Paper.pdf.
- G7. 2025. "Kananaskis Common Vision for the Future of Quantum Technologies." June 17. <https://g7.canada.ca/assets/ea689367/Attachments/NewItems/pdf/g7-summit-statements/quantum-en.pdf>.
- Gaida, Jamie, Jennifer Wong-Leung, Stephan Robin and Danielle Cave. 2023. *ASPI's Critical Technology Tracker: The global race for future power*. Policy Brief Report No. 69/2023. Canberra, Australia: Australian Strategic Policy Institute. www.aspi.org.au/report/critical-technology-tracker/.
- Ghysels, Eric, Jack Morgan and Hamed Mohammadbagherpoor. 2025. "On Quantum and Quantum-Inspired Maximum Likelihood Estimation and Filtering of Stochastic Volatility Models." SSRN. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5274549.
- Gilboa, Dar, Siddhartha Jain and Jarrod McClean. 2025. "Consumable Data Via Quantum Communication." SSRN. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5393544.
- Goorden, Sebastianus A., Marcel Horstmann, Allard P. Mosk, Boris Škorić and Pepijn W. H. Pinkse. 2014. "Quantum-secure authentication of a physical unclonable key." *Optica* 1 (6): 421–24. <https://opg.optica.org/optica/fulltext.cfm?uri=optica-1-6-421&id=306292>.
- Gorney, Simon, Borja Muñoz and Jacob Sherson. 2025. "Quantum technology master's: a shortcut to the quantum industry?" *EPJ Quantum Technology* 12, 2. <https://doi.org/10.1140/epjqt/s40507-024-00299-x>.

- Gopasana, Syamasundar, Shreyas Ramesh and Arunima Sarkar. 2025. “Quantum Technologies: Key Strategies and Opportunities for Financial Services Leaders.” White Paper. July. Geneva, Switzerland: World Economic Forum.
https://reports.weforum.org/docs/WEF_Quantum_Technologies_Key_Strategies_and_Opportunities_for_Financial_Services_Leaders_2025.pdf.
- Gouvernement de France. 2023. *France National Quantum Strategy*. Annual Report. March. Paris, France: Gouvernement de France. www.info.gouv.fr/upload/media/organization/0001/01/sites_default_files_contenu_piece-jointe_2023_04_france2030_quantique_rapport_activite_2022_vdef2.pdf.
- Government of Canada. 2025. “Order Amending the Export Control List: SOR/2025-89.” *Canada Gazette*, Part II, vol. 159, no. 7. <https://gazette.gc.ca/rp-pr/p2/2025/2025-03-26/html/sor-dors89-eng.html>.
- Government of Japan. 2021. *Science, Technology, and Innovation Basic Plan*. March 26. Tokyo, Japan: Government of Japan. www8.cao.go.jp/cstp/english/sti_basic_plan.pdf.
- Gruppo di lavoro per la strategia quantistica italiana. 2025. *Strategia Italiana per le Tecnologie Quantistiche*. Ministero dell’Università e della Ricerca. www.mur.gov.it/sites/default/files/2025-03/QIS_master_for_consultation.pdf.
- Hart, Brian, Bonny Lin, Samantha Lu, Hannah Price, Yu-Jie (Grace) Liao and Matthew Slade. 2024. “Is China a Leader in Quantum Technologies?” *ChinaPower*, August 14. <https://chinapower.csis.org/china-quantum-technology/>.
- Hellstern, Gerhard and Esra Yeniaras. 2025. “Quantum Leap in Finance: Economic Advantages, Security, and Post-Quantum Readiness.” Preprint, arXiv, August 29. <https://doi.org/10.48550/arXiv.2508.21548>.
- Herman, Dylan, Cody Googin, Xiaoyuan Liu, Alexey Galda, Ilya Safro, Yue Sun, Marco Pistoia et al. 2022. “A Survey of Quantum Computing for Finance.” Preprint, arXiv, June 27. <https://doi.org/10.48550/arXiv.2201.02773>.
- — —. 2023. “Quantum computing for finance.” *Nature Reviews Physics* 5 (8): 450–65. <https://doi.org/10.1038/s42254-023-00603-1>.
- Hmadi, Antonia and Jeroen Gorenweg-Lau. 2024. “China’s long view on quantum tech has the US and EU playing catch-up.” Mercator Institute for China Studies, December 12. <https://merics.org/en/report/chinas-long-view-quantum-tech-has-us-and-eu-playing-catch>.
- HSBC. 2023a. “HSBC becomes first bank to join the UK’s pioneering commercial quantum secure metro network.” Media release, July 5. www.hsbc.com/news-and-views/news/media-releases/2023/hsbc-becomes-first-bank-to-join-the-uks-pioneering-commercial-quantum-secure-metro-network.
- — —. 2023b. “HSBC pioneers Quantum protection for AI-powered FX trading.” Media release, December 6. www.hsbc.com/news-and-views/news/media-releases/2023/hsbc-pioneers-quantum-protection-for-ai-powered-fx-trading.
- — —. 2024. “HSBC pilots quantum-safe technology for tokenised gold.” Media release, September 19. www.hsbc.com/news-and-views/news/media-releases/2024/hsbc-pilots-quantum-safe-technology-for-tokenised-gold.
- Hupel, Lars and Makan Rafiee. 2023. “How does post-quantum cryptography affect Central Bank Digital Currency?” Preprint, arXiv, December 18. <https://doi.org/10.48550/arXiv.2308.15787>.

- ICBC. 2017. "ICBC Succeeds in Applying Thousand-km-level Quantum Communication Technology." News update, May 1. www.icbc-ltd.com/icbc/en/newsupdates/icbc%20news/ICBCSucceedsinApplyingThousandkmlevelQuantumCommunicationTechnology.htm.
- ID Quantique. 2017. "Securing Network for Disaster Recovery." Geneva, Switzerland: ID Quantique. <https://cdn-adepci1.actonsoftware.com/acton/cdna/11868/f-0211/1/1>.
- — —. 2019. "ERNIE 5 Goes Quantum: Quantis True Random Number Generator." Geneva, Switzerland: ID Quantique. <https://cdn-adepci1.actonsoftware.com/acton/cdna/11868/f-7d9b3e78-4571-4549-964b-1209cb2bd6ac/1/2>.
- — —. 2020. "The Quantum Vault: Securing Custody of Digital Assets." Geneva, Switzerland: ID Quantique. <https://cdn-adepci1.actonsoftware.com/acton/cdna/11868/f-b2d8657c-6132-434c-8f38-09ee1ed5d9bd/1/1>.
- Indian Computer Emergency Response Team. 2025. "Transitioning To Quantum Cyber Readiness." White Paper. <https://static.pib.gov.in/WriteReadData/specificdocs/documents/2025/jul/doc2025714585911.pdf>.
- Innovation, Science and Economic Development Canada. 2022. *Canada's National Quantum Strategy*. Ottawa, ON: Government of Canada. <https://ised-isde.canada.ca/site/national-quantum-strategy/sites/default/files/attachments/2022/NQS-SQN-eng.pdf>.
- Institute of Commercial Cryptography Standards. 2025. Press release, February 5. www.niccs.org.cn/en/.
- Interbank Convention for Automation. 2024. *Quantum technologies in the banking sector*. May. www.cipa.it/altre-pubblicazioni/gruppi-lavoro/tecnologiequantistiche/quantumtechnologies.pdf.
- ITU. 2021. "Standards bodies to coordinate contributions to quantum information technology." News, March 17. www.itu.int/hub/2021/03/standards-bodies-to-coordinate-contributions-to-quantum-information-technology/.
- Katwala, Amit. 2025. "The Quantum Apocalypse Is Coming. Be Very Afraid." *Wired*, March 24. www.wired.com/story/q-day-apocalypse-quantum-computers-encryption/.
- Kaur, Maninder and Araceli Venegas-Gomez. 2022. "Defining the quantum workforce landscape: a review of global quantum education initiatives." Preprint, arXiv, April 21. <https://arxiv.org/abs/2202.08940>.
- Kearney, Joseph J. and Carlos A. Perez-Delgado. 2021. "Vulnerability of blockchain technologies to quantum attacks." *Array* 10: 100065. <https://doi.org/10.1016/j.array.2021.100065>.
- Khan, Faisal Shah, Norbert M. Linke, Anton Trong Than and Dror Baron. 2025. "Quantum Advantage in Trading: A Game-Theoretic Approach." *Quantum Economics and Finance* 2 (1). <https://doi.org/10.1177/29767032251333418>.
- Krelina, Michal. 2021. "Quantum technology for military applications." *EPJ Quantum Technology* 8 (24). <https://link.springer.com/article/10.1140/epjqt/s40507-021-00113-y>.
- Kung, Johnny and Murium Fancy. 2021. *A Quantum Revolution: Report on Global Policies for Quantum Technology*. April. Toronto, ON: Canadian Institute for Advanced Research. <https://cifar.ca/cifarnews/2021/04/07/a-quantum-revolution-report-on-global-policies-for-quantum-technology/>.

- Lewis, James Andrew and Georgia Wood. 2023. "Quantum Technology: Applications and Implications." Washington, DC: Center for Strategic & International Studies. www.csis.org/analysis/quantum-technology-applications-and-implications.
- Mandelbaum, Ryan, Jay Gambetta, Jerry Chow, Tushar Mittal, Theodore J. Yoder, Andrew Cross and Matthias Steffen. 2025. "How IBM will build the world's first large-scale, fault-tolerant quantum computer." *Quantum Research* (blog), June 10. www.ibm.com/quantum/blog/large-scale-ftqc.
- Mans, Ulrich. 2025. "Quantum Supply Chains: A Test Case for a New Economic World Order." *Just Security*, August 27. www.justsecurity.org/115813/quantum-new-economic-world-order/.
- Marin. 2024. "Quantum Technologies and Quantum Computing in Russia." *PostQuantum*, December 26. <https://postquantum.com/quantum-computing/quantum-russia/>.
- Markov, Vanio Slavov, Vladimir Rastunkov and Juan I. Adame. 2024. "Quantum Generative Models of Mid-Price Movement in Limit Order Books." *ICAFIF '24 Proceedings of the 5th ACM International Conference on AI in Finance*, 737–44. <https://dl.acm.org/doi/10.1145/3677052.3698679>.
- Marsden, Danica, Ajit Desai, Adriano Baldeschi, Luca Bastianelli, Giuseppe Bruno, Riccardo Russo and Valerio Astuti. 2025. "Liquidity Optimization in Gross Settlement Systems with Quantum Reordering: Application to Target2." Preprint, SSRN, July 23. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5363714.
- Martini, Francesco, Daniele Lizzio Bosco, Carlo Barbanera, Serena Bernardini, Giacomo Ranieri, Francesca Cibrario, Davide Corbelleto et al. 2025. "Securities Transaction Settlement Optimization on superconducting quantum devices." Preprint, arXiv, January 15. <https://arxiv.org/abs/2501.08794>.
- McKinsey & Company. 2024. *Quantum Technology Monitor*. April. www.mckinsey.com/~media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/steady%20progress%20in%20approaching%20the%20quantum%20advantage/quantum-technology-monitor-april-2024.pdf.
- — —. 2025. *Quantum Technology Monitor*. June. www.mckinsey.com/capabilities/tech-and-ai/our-insights/the-year-of-quantum-from-concept-to-reality-in-2025.
- McMahon, Christopher, Donald McGillivray, Ajit Desai, Francisco Rivadeneyra, Jean-Paul Lam, Thomas Lo, Danica Marsden et al. 2022. "Improving the Efficiency of Payments Systems Using Quantum Computing." Staff Working Paper 2022-53. <https://doi.org/10.34989/swp-2022-53>.
- Ministry of Science and ICT. 2023a. *Korea's National Quantum Strategy*. June 27. https://quantuminkorea.org/wp-content/uploads/2024/06/Koreas-National-Quantum-Strategy-2023_c.pdf.
- — —. 2023b. "Act on Promotion of Quantum Science, Technology, and Industry Takes Effect." Press release. www.msit.go.kr/eng/bbs/view.do?sCode=eng&mId=4&mPid=2&pageIndex=&bbsSeqNo=42&nttSeqNo=1053&searchOpt=ALL&searchTxt=.
- Mohr, Niko, Kiera Peltz, Rodney Zimmel and Matija Zesko. 2022. "Five lessons from AI on closing quantum's talent gap — before it's too late." McKinsey & Company. December 1. www.mckinsey.com/capabilities/mckinsey-digital/our-insights/five-lessons-from-ai-on-closing-quantums-talent-gap-before-its-too-late.

- Murphy, Michael P. A. and Tracey Forrest. 2025. *Principles for Quantum Governance: Kananaskis and Beyond*. Policy Brief No. 207. Waterloo, ON: CIGI. www.cigionline.org/publications/principles-for-quantum-governance-kananaskis-and-beyond/.
- Murphy, Michael P. A., Tracey Forrest and Paul Samson. 2025. *From Peace Dividend to Defence Dividend: Dual-Use, Quantum and NATO Targets*. CIGI Paper No. 333. Waterloo, ON: CIGI. www.cigionline.org/publications/from-peace-dividend-to-defence-dividend-dual-use-quantum-and-nato-targets/.
- National Cyber Security Centre. 2020. “Preparing for Quantum-Safe Cryptography.” White Paper. November 11. www.ncsc.gov.uk/whitepaper/preparing-for-quantum-safe-cryptography.
- NICT. 2022. “Successful Joint Verification Test for Low Latency Transmission of Highly Confidential Data Using Quantum Cryptography for Large-volume Financial Transaction Data.” Press release, February 18. www.nict.go.jp/en/press/2022/02/18-1.html.
- Nielsen, Michael A. and Isaac L. Chuang. 2000. *Quantum Computation and Quantum Information*. Cambridge, UK: Cambridge University Press.
- Nili, Cameron, Tom Patterson and Carl Dukatz. 2024. “Safeguarding central bank digital currency systems in the post-quantum computing age.” World Economic Forum, May 21. www.weforum.org/stories/2024/05/safeguarding-central-bank-digital-currency-systems-post-quantum-age/.
- NIS Cooperation Group. 2025. “A Coordinated Implementation Roadmap for the Transition to Post-Quantum Cryptography.” Part 1, Version 1.1, EU PQC Workstream. June 11. <https://ec.europa.eu/newsroom/dae/redirection/document/117507>.
- NIST. 2024. “NIST Releases First 3 Finalized Post-Quantum Encryption Standards.” News, August 13. www.nist.gov/news-events/news/2024/08/nist-releases-first-3-finalized-post-quantum-encryption-standards.
- OECD. 2025a. “A Quantum Technologies Policy Primer.” OECD Digital Economy Papers No. 371. January. Paris, France: OECD. <https://doi.org/10.1787/fd1153c3-en>.
- — —. 2025b. “An Overview of National Strategies and Policies for Quantum Technologies.” OECD Digital Economy Papers No. 379. December. Paris, France: OECD. www.oecd.org/en/publications/an-overview-of-national-strategies-and-policies-for-quantum-technologies_5e55e7ab-en.html.
- Omaar, Hodan and Martin Makaryan. 2024. “How Innovative Is China in Quantum?” September. Information Technology & Innovation Foundation. www2.itif.org/2024-chinese-quantum-innovation.pdf.
- Open Quantum Institute. 2024. *Intelligence Report on Quantum Diplomacy for the Sustainable Development Goals (SDGs)*. 2nd ed. October. Geneva, Switzerland: Geneva Science and Diplomacy Anticipator. https://open-quantum-institute.cern/wp-content/uploads/2025/11/Intelligence_Report-2024.pdf.
- — —. 2025. *Intelligence Report on Quantum Diplomacy in Action 2025–2026*. Geneva, Switzerland: Geneva Science and Diplomacy Anticipator. <https://open-quantum-institute.cern/wp-content/uploads/2025/11/Intelligence-Report-2025.pdf>.

- Parker, Edward. 2021. *Commercial and Military Applications and Timelines for Quantum Technology*. Research Report. Santa Monica, CA: RAND Corporation. www.rand.org/content/dam/rand/pubs/research_reports/RRA1400/RRA1482-4/RAND_RRA1482-4.pdf.
- Parker, Edward, Daniel Gonzalez, Ajay K. Kocchar, Sydney Litterer, Kathryn O'Connor, Jon Schmid, Keller Scholl et al. 2022. *An Assessment of the U.S. and Chinese Industrial Bases in Quantum Technology*. Research Report. Santa Monica, CA: RAND Corporation. www.rand.org/pubs/research_reports/RRA869-1.html.
- Parker, Edward, Richard Silberglitt, Daniel Gonzales, Natalia Henriquez Sanchez, Justin W. Lee, Lindsay Rand, Jon Schmid et al. 2023. *An Assessment of U.S.-Allied Nations' Industrial Bases in Quantum Technology*. Santa Monica, CA: RAND Corporation. www.rand.org/pubs/research_reports/RRA2055-1.html.
- Patel, Raj G., Chia-Wei Hsing, Serkan Şahin, Samuel Palmer, Saeed S. Jahromi, Shivam Sharma, Tomas Dominguez et al. 2024. "Quantum-Inspired Tensor Neural Networks for Option Pricing." Preprint, arXiv, March 10. <https://arxiv.org/abs/2212.14076>.
- Patton, Susannah, Jack Sato and Hervé Lemahieu. 2024. *Lowy Institute Asia Power Index: 2024 Key Findings Report*. Sydney, Australia: Lowy Institute. <https://power.lowyinstitute.org/downloads/lowy-institute-2024-asia-power-index-key-findings-report.pdf>.
- Perrazzelli, Alessandra. 2024. "Alessandra Perrazzelli: Steering the transition to a quantum-safe world. An internationally coordinated approach." Keynote speech by Alessandra Perrazzelli, Deputy Governor of the Bank of Italy, at the G7 conference on "Building the Quantum Safe Financial System: What Role for Authorities and for the Private Sector?", Rome, September 24. www.bis.org/review/r240924s.htm.
- Pistoia, Marco and Suresh Shetty. n.d. "JPMorgan Chase, Toshiba and Ciena Build the First Quantum Key Distribution Network Used to Secure Mission-Critical Blockchain Application." *Tech Blog*. www.jpmmorgan.com/technology/technology-blog/jpmc-toshiba-ciena-build-first-quantum-key-distribution-network-critical-blockchain-application.
- Priazhkina, Sofia, Samuel Palmer, Pablo Martín-Ramiro, Román Orús, Samuel Mugel and Vladimir Skavysh. 2024. "Digital Payments in Firm Networks: Theory of Adoption and Quantum Algorithm." Bank of Canada Staff Working Paper 2024-17. May. www.bankofcanada.ca/2024/05/staff-working-paper-2024-17/.
- Prime Minister of Canada. 2025. "Joint statement: Enduring Partnership, Ambitious Agenda." News statement, June 23. www.pm.gc.ca/en/news/statements/2025/06/23/joint-statement-enduring-partnership.
- Puel, Jean-Marc and Natasza Mikołajczak. 2025. "The Global Quantum Talent Shortage: Who Will Lead the Future?" Vector Synergy, March 17. www.vectorsynergy.com/post/the-global-quantum-talent-shortage.
- Purohit, Abhishek, Maninder Kaur, Zeki Can Seskir, Matthew T. Posner and Araceli Venegas-Gomez. 2024. "Building a quantum-ready ecosystem." *IET Quantum Communication* 5 (1): 1–18. <https://doi.org/10.1049/qtc2.12072>.
- QED-C. 2025. *2025 State of the Global Quantum Industry Report*. March. Arlington, VA: SRI International. <https://quantumconsortium.org/publication/2025-state-of-the-global-quantum-industry-report/>.

- Qi, Wei. 2023. "A Brief Introduction to the Latest Progress of China's QKD Industry." ETSI/IQC Quantum Safe Cryptography Event, February 14. https://docbox.etsi.org/Workshop/2023/02_QUANTUMSAFECRYPTOGRAPHY/TECHNICALTRACK/WORLDTOUR/CASQUANTUMNETWORK_QI.pdf.
- Quanta Intelligence. 2024. "Japanese Tech Firms Invest in Quantum Computing." *Quanta AI* (blog), December 4. <https://quantaintelligence.ai/2024/12/04/technology/japanese-tech-firms-invest-in-quantum-computing>.
- Quantum Delta NL. 2019. *National Agenda for Quantum Technology*. September. Delft, the Netherlands: Quantum Delta NL. <https://assets.quantum-delta.prod.verveagency.com/assets/national-agenda-for-quantum-technology.pdf>.
- — —. n.d. "Quantum Delta NL in a nutshell." Delft, the Netherlands: Quantum Delta NL. [https://assets.quantum-delta.prod.verveagency.com/assets/a-summary-of-the-quantum-delta-nl-programme-2021--2027-\(incl.-budget\).pdf](https://assets.quantum-delta.prod.verveagency.com/assets/a-summary-of-the-quantum-delta-nl-programme-2021--2027-(incl.-budget).pdf).
- Quantum Ecosystems Technology Council of India. 2023. *The Quantum Value Chain Report*. December. <https://qetci.org/wp-content/uploads/2024/01/Quantum-Value-Chain-Report-2023.pdf>.
- Quantum Insider. 2026. "The Quantum Insider Projects \$1 Trillion In Economic Impact From Quantum Computing By 2035." January 7. <https://thequantuminsider.com/2024/09/13/the-quantum-insider-projects-1-trillion-in-economic-impact-from-quantum-computing-by-2035/>.
- Quantum Xchange. 2019. "Enhanced Capacity of First Quantum-Secured Network in the U.S. Makes Next-Generation Secure Communications Practical and Affordable for Enterprise Users." Press release, April 25. <https://murat-staging.ceo.ca/@newswire/quantum-xchange-tests-toshibas-quantum-key-distribution>.
- QURECA. 2025. "Quantum Initiatives Worldwide." October 15. www.quireca.com/quantum-initiatives-worldwide/.
- Randazzese, Lucien, Claire Lecornu, Jessica Avery, Krystal Bouverot and Shay Moore. 2023. *Quantum Technology Manufacturing Roadmap: Scaling Up Quantum*. October. Menlo Park, CA: SRI International Center for Innovation Strategy and Policy. www.sri.com/wp-content/uploads/2023/11/QTMR-Final-Report-of-Needs-Capabilities-and-Gaps-v5.pdf.
- Riley, Duncan. 2017. "Russian group delivers the first unhackable quantum-safe blockchain." Silicon Angle, May 24. <https://siliconangle.com/2017/05/24/russian-group-delivers-first-unhackable-quantum-safe-blockchain/>.
- Rosenbach, Eric, Lea Baltussen, Eleanor Crane, Ethan Kessler, Lukasz Kolodziej, Ethan Lee, Alexander Meyer et al. 2025. *Critical and Emerging Technologies Index*. June. Cambridge, MA: Belfer Center for Science and International Affairs, Harvard Kennedy School. www.belfercenter.org/sites/default/files/2025-06/DETS_Critical%20and%20Emerging%20Technologies%20Index%20Report_June%202025.pdf.
- Ruane, Jonathan, Elif Kiesow, Johannes Galatsanos, Carl Dukatz, Edward Blomquist and Prashant Shukla. 2025. *The Quantum Index Report 2025*. May. MIT Initiative on the Digital Economy. Cambridge, MA: MIT.
- Ruddock, Callum. 2021. "The Future of Finance is Quantum." QURECA, February 8. www.quireca.com/the-future-of-finance-is-quantum/.

- Sakuler, Wolfgang, Johannes M. Oberreuter, Riccardo Aiolfi, Luca Asproni, Branislav Roman and Jürgen Schiefer. 2023. "A real world test of Portfolio Optimization with Quantum Annealing." Preprint, arXiv, March 22. <https://arxiv.org/abs/2303.12601>.
- SandboxAQ. 2025. "AI, Quantum, and the Future of Financial Markets." March 6. www.sandboxaq.com/post/ai-quantum-and-the-future-of-financial-markets.
- Santander. 2024. "The future for customer data security: post-quantum cryptography." March 18. www.santander.com/en/stories/the-future-for-customer-data-security-post-quantum-cryptography.
- Secretariat of Science, Technology and Innovation Policy. 2023. "Strategy of Quantum Future Industry Development: Summary." April. www8.cao.go.jp/cstp/english/strategy_r08.pdf.
- Smith-Goodson, Paul. 2023. "JPMorgan Chase And QC Ware Collaborate On Quantum Finance Breakthrough In Deep Hedging." *Forbes*, May 22. www.forbes.com/sites/moorinsights/2023/05/22/jpmorgan-chase-and-qc-ware-collaborate-on-quantum-finance-breakthrough-in-deep-hedging/.
- So-young, Ahn. 2025. "Korea requires trade approval for quantum computers, AI semiconductors starting 28th." *ChosunBiz*, February 23. <https://biz.chosun.com/en/en-policy/2025/02/23/6QXOAC4SUJBVHIMKEJHVMTSRE4/>.
- SpinQ. 2025. "Huaxia Bank Partners with SpinQ to Develop Quantum AI Models for Smarter Commercial Banking Decisions." *News*, January 9. www.spinquanta.com/news-detail/huaxia-bank-partners-with-spinq-to-develop-quantum-ai-models20250109075044.
- Suleyman, Mustafa. 2023. *The Coming Wave: Technology, Power, and the Twenty-First Century's Greatest Dilemma*. New York, NY: Crown.
- Swayne, Matt. 2025a. "Governments Face Key Challenges In Quantum Technology Policy, OECD Report Finds." *Quantum Insider*, May 9. <https://thequantuminsider.com/2025/02/08/governments-face-key-challenges-in-quantum-technology-policy-oecd-report-finds/>.
- — —. 2025b. "Quantum Network Goes The Distance Using Existing Telecom Infrastructure." *Quantum Insider*, April 24. <https://thequantuminsider.com/2025/04/24/quantum-network-goes-the-distance-using-existing-telecom-infrastructure/>.
- — —. 2025c. "Ueno Bank Brings Its 2.2 Million Customers Quantum-Resistant Banking With SignQuantum And QANplatform." *Quantum Insider*, September 12. <https://thequantuminsider.com/2025/09/12/ueno-bank-brings-its-2-2-million-customers-quantum-resistant-banking-with-signquantum-and-qanplatform/>.
- Tan, Teik Guan, Pawel Szalachowski and Jianying Zhou. 2022. "Challenges of post-quantum digital signing in real-world applications: a survey." *International Journal of Information Security* 21 (4): 937–52. <https://doi.org/10.1007/s10207-022-00587-6>.
- Terra Quantum. 2025. "Terra Quantum and BBVA Complete Pilot for Advanced Exotic Derivatives Pricing Solution." News release, February 6. <https://terraquantum.swiss/news/terra-quantum-and-bbva-complete-pilot-for-advanced-exotic-derivatives-pricing-solution/>.

- The Moscow Times*. 2023. "Russia's Quantum Patent Applications Decline Amid Sanctions." June 14. www.themoscowtimes.com/2023/06/14/russias-quantum-patent-applications-decline-amid-sanctions-a81499.
- Tong, Zhang. 2023. "Chinese financial industry banks on quantum computing to help combat fraud." *South China Morning Post*, February 4. www.scmp.com/news/china/science/article/3209016/chinese-financial-industry-banking-quantum-computing-help-combat-fraud.
- U.S.-China Economic and Security Review Commission. 2024. *2024 Report to Congress of the U.S.-China Economic and Security Review Commission*. 118th Congress, 2nd Session. November. www.uscc.gov/sites/default/files/2024-11/2024_Annual_Report_to_Congress.pdf.
- Vermeer, Michael J. D., Chad Heitzenrater, Edward Parker, Alvin Moon, Dominique Lumpkin and Jalal Awan. 2024. "Evaluating cryptographic vulnerabilities created by quantum computing in industrial control systems." *Journal of Critical Infrastructure Policy* 5 (2): 88–110. <https://doi.org/10.1002/jci3.12024>.
- Vu, Dinh-Long, Bin Cheng and Patrick Rebstrost. 2025. "Low-depth Amplitude Estimation without Really Trying." *ACM Transactions on Quantum Computing* 6 (4): 1–23. <https://doi.org/10.1145/3748666>.
- Wassenaar Arrangement Secretariat. 2023. *List of Dual-Use Goods and Technologies and Munitions List*. Public Documents, vol. 2. December. Vienna, Austria: Wassenaar Arrangement Secretariat. www.wassenaar.org/app/uploads/2023/12/List-of-Dual-Use-Goods-and-Technologies-Munitions-List-2023-1.pdf.
- World Bank. 2025. *Global Economic Prospects, June 2025*. Washington, DC: World Bank. <https://hdl.handle.net/10986/43168>.
- World Economic Forum. 2023. "Pathways to the Regulation of Crypto-Assets: A Global Approach." White Paper. May. Geneva, Switzerland: World Economic Forum. www3.weforum.org/docs/WEF_Pathways_to_the_Regulation_of_Crypto_Assets_2023.pdf.
- — —. 2024a. "Safeguarding central bank digital currency systems in the post-quantum computing age." May 21. www.weforum.org/stories/2024/05/safeguarding-central-bank-digital-currency-systems-post-quantum-age/.
- — —. 2024b. *Digital Assets Regulation: Insights from Jurisdictional Approaches*. Insight Report. October. Geneva, Switzerland: World Economic Forum. www3.weforum.org/docs/WEF_Digital_Assets_Regulation_2024.pdf.
- — —. 2025. "Quantum Technologies: Key Strategies and Opportunities for Financial Services Leaders." White Paper. July. Geneva, Switzerland: World Economic Forum. https://reports.weforum.org/docs/WEF_Quantum_Technologies_Key_Strategies_and_Opportunities_for_Financial_Services_Leaders_2025.pdf.



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