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ARTICLE

Quantum Computing in Finance: Regulatory Readiness, Legal Gaps, and the Future of Secure Tech Innovation

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Abstract

Quantum computing is rapidly advancing from a theoretical possibility to a transformative force in financial systems. With its high-dimensional computational capacity, quantum technology is promising for enhancing risk modelling, fraud detection and transaction efficiency. However, it also seriously threatens cryptographic security, regulatory coherence and systemic stability. This paper critically analyses the risks introduced by cryptographically relevant quantum computers and assesses the readiness of legal and institutional frameworks to respond. Focusing on the UK financial regulatory environment, the study proposes a quantum-safe integration roadmap grounded in post-quantum cryptography, adaptive regulatory models and sector-wide governance strategies. The paper argues for anticipatory regulation that embeds enforceable standards and strategic collaboration across public and private stakeholders through an interdisciplinary approach combining legal analysis and financial risk modelling. The UK's leadership in quantum policy positions it to shape international norms in secure quantum adoption. Finally, the paper offers an analytical framework to ensure that quantum innovation reinforces rather than destabilises data integrity, financial resilience and public trust.

Keyword: Post-quantum cryptography; quantum computing; quantum finance; quantum-safe frameworks; regulatory challenges

I. Introduction

Quantum computing is rapidly transitioning from theoretical possibility to technological reality, redefining the boundaries of computational power and reshaping industries. Emerging from foundational insights in the 1980s by physicists like Richard Feynman, quantum computing has evolved to leverage principles such as superposition and entanglement, allowing qubits to perform calculations that classical computers would find impossible.[1] Milestones like the development of machines capable of processing up to 1,000 qubits signal an exponential leap, with companies like Atom Computing and IBM pioneering advancements that predict systems with 2,000 qubits by 2033.[2] However, the financial sector is uniquely exposed to these exponential developments, which could pose an existential threat to the cryptographic infrastructure underpinning modern financial systems.[3]

[1] Raphael Auer and others, *Quantum Computing and the Financial System: Opportunities and Risks* (BIS Papers No 149, Monetary and Economic Department, October 2024).

[2] IBM, *IBM Quantum: Development & Innovation Roadmap* (White Paper, 2024).

[3] Ayben Koy and Andaç Batur Çolak, "The Intraday High-Frequency Trading with Different Data Ranges: A Comparative Study with Artificial Neural Network and Vector Autoregressive Models" (2024) 2(3) *Bon View Adv Artif Intell Exp Syst* <https://doi.org/10.47852/bonviewAAES32021325> (accessed 16 May 2025).

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While quantum computing promises to enhance portfolio optimisation, liquidity management and risk modelling, it also introduces acute vulnerabilities in data confidentiality and algorithmic reliability. Algorithms such as Shor's and Grover's threaten to compromise widely used encryption protocols, including RSA and ECC, raising the risk of a so-called "Q-Day," when previously secure financial data may be decrypted retrospectively or exploited in real-time.[4] These risks are not theoretical; they signal an impending shift in the security assumptions upon which financial regulation, compliance, and market integrity depend.

Despite rapid technical advancements, financial services' regulatory architecture remains ill-equipped to respond to quantum-induced risks. Regulatory mechanisms such as the UK's Financial Services and Markets Act 2023 (FSMA), the General Data Protection Regulation (GDPR), and the EU's Digital Operational Resilience Act (DORA) do not yet incorporate enforceable standards for post-quantum resilience. Likewise, while ambitious, the UK's National Quantum Strategy prioritises innovation and investment without clearly articulating institutional responsibilities, enforcement mechanisms, or liability models in the event of quantum-triggered disruption.[5]

This paper asks: What legal, regulatory, and institutional mechanisms are needed to enable a secure and accountable transition to a quantum-safe financial system? In response, it advances three core contributions. First, it diagnoses how quantum threats expose structural gaps in current financial regulation. Second, it offers a normative framework for adaptive regulatory design grounded in legal principles such as proportionality, precaution and institutional accountability. Third, it proposes the formation of a Quantum-Safe Financial Task Force to coordinate standard-setting, cross-sectoral enforcement and post-quantum cryptographic migration within the UK.

To capture the complexity of quantum computing's legal and systemic implications, this paper provides a cross-disciplinary framework that fuses doctrinal legal reasoning with insights from cryptographic science, financial systems analysis and regulatory policy studies. It engages with emerging standards (such as the National Institute of Standards and Technology, i.e. NIST's post-quantum protocols), comparative legal reforms, and institutional risk responses in the UK, EU and US, offering a forward-looking critique of regulatory preparedness.

The stakes are both legal and systemic. Failure to act pre-emptively may expose financial infrastructures to retrospective data breaches, regulatory incoherence and cascading market instability. Yet, with timely institutional coordination, legally anchored governance and anticipatory regulatory design, the transition to quantum-enabled finance can be managed safely, ethically and strategically. This paper aims to contribute to that goal.

I. Methodology

This study employs an interdisciplinary methodology to critically evaluate the transformative potential and regulatory challenges of quantum computing within the financial sector. The research adopts a multi-layered approach to address quantum technology's technical, systemic and governance dimensions by integrating legal doctrinal analysis, financial risk modelling, cryptographic security assessments and policy benchmarking. The methodology is structured to ensure analytical depth, coherence and practical relevance, aligning with the dual objectives of advancing scholarly discourse

[4] Ibid.

[5] Ayben Koy and Andaç Batur Çolak, "Predicting Stock Market Index and Credit Default Swap Spreads Using Artificial Intelligence and Determining Nonlinear Relations" (2023) 1 *Arch of Adv Eng Sci* <https://doi.org/10.47852/bonviewAAES32021366> (accessed 10 June 2025).

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and informing policy innovation. Its novelty is bridging technical quantum advancements with actionable financial governance frameworks, a gap in the existing literature, while pioneering systemic risk models for quantum-driven market instability.

The legal and regulatory analysis adopts a doctrinal framework to dissect statutory and policy responses to quantum computing risks. Primary legal instruments, including the UK's Financial Services and Markets Act 2023, Data Protection Act 2018, the Digital Operational Resilience Act 2022 and the EU's Cybersecurity Act (Regulation 2019/881), are scrutinised to evaluate operational resilience, encryption standards and critical infrastructure protection provisions. A comparative jurisdictional review benchmarks the UK's regulatory agility against the US National Quantum Initiative Act (2018) and the EU's Quantum Technologies Flagship Programme, identifying disparities in harmonising encryption mandates and liability frameworks for quantum-related data breaches. Judicial precedents are deliberately excluded due to the nascent state of quantum-specific litigation, ensuring the analysis remains forward-looking and policy-centric. This comparative analysis uniquely highlights the UK's potential to set global standards for quantum-safe finance, a contribution absent in prior sector-specific studies.

Financial risk assessment is conducted through mixed-method case studies to quantify systemic implications. Peer-reviewed quantum-enhanced models, such as Monte Carlo simulations for portfolio risk calculations, are evaluated for their computational advantages over classical systems.[6] The Bank of Canada's 2022 pilot study on quantum-driven liquidity optimisation, which demonstrated a 17 per cent efficiency gain, is critically analysed to assess scalability and market stability implications.[7] High-frequency trading risks are modelled using historical precedents like the 2010 Flash Crash, contextualised within the SEC's 2023 proposals for algorithmic trading safeguards. These case studies are selected based on empirical validation in journals such as IEEE Transactions on Quantum Engineering and their alignment with systemic risk frameworks outlined by the Financial Stability Board (FSB).[8] This paper pioneers a risk-assessment paradigm that transcends conventional cryptographic threat models by linking quantum-accelerated trading to systemic instability.

The cryptographic security assessment maps vulnerabilities in current encryption protocols, focusing on RSA-2048 and ECC-256, against quantum decryption capabilities demonstrated by Shor's algorithm. This is complemented by evaluating post-quantum cryptographic (PQC) migration strategies, including lattice-based and hash-based algorithms, benchmarked against the UK National Cyber Security Centre's (NCSC) 2023 guidelines. Blockchain integrity is analysed through the lens of quantum threats to SHA-256 hashing in Bitcoin, informed by Nakamoto's consensus model.[9] Technical standards such as NIST's FIPS 203 draft are cross-referenced with regulatory mandates like the EU's Digital Operational Resilience Act to propose a risk-tiered migration framework for financial institutions. This approach uniquely bridges technical cryptographic advancements with regulatory compliance, offering a roadmap absent in siloed technical or policy studies.

Policy recommendations are derived from a triangulated analysis of international regulatory benchmarks, industry practices and stakeholder consultations. The UK's National Quantum Strategy (2023), the US Executive Order on Quantum Computing (2022),

[6] Belal Ehsan Baaquie, "Quantum Computations and Option Pricing" in *Looking Beyond the Frontiers of Science* (July 2022) 159–79.

[7] C McMahon and others, "Improving the Efficiency of Payments Systems Using Quantum Computing" (Bank of Canada Staff Working Paper No 2022-53, December 2022).

[8] D Egger and others, "Quantum Computing for Finance: State-of-the-Art and Future Prospects" (2020) 1 *IEEE Trans Quantum Eng* 3101724.

[9] Paweł Weichbroth and others, "A View on the State-of-the-Art Research and Current Developments" (2023) 23(6) Sensors 3155.

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and the EU's Cyber Resilience Act (2024) are compared to identify best practices in encryption migration and systemic risk mitigation. Insights from the Bank for International Settlements (BIS Project Leap), IBM's Quantum Security Whitepaper (2023), and the Financial Conduct Authority's consultations are synthesised to develop the proposed Quantum-Safe Financial Task Force framework. This framework advocates phased encryption migration aligned with NIST's standardisation timeline, market circuit breakers inspired by SEC Rules and cross-border governance mechanisms leveraging the G7's 2023 Hiroshima Quantum Principles.[10] These recommendations address a critical gap in static, compliance-driven policy literature by prioritising adaptive regulation and public-private collaboration.[11]

The study acknowledges limitations inherent in its scope and methodology. Empirical constraints due to the absence of large-scale quantum computers are mitigated by reliance on peer-reviewed simulations, such as Google's 2023 quantum supremacy experiments.[12] While the analysis prioritises the UK, EU and US regulatory landscapes, emerging jurisdictions like China and the National Laboratory for Quantum Information Sciences are considered critical future comparators. Rapid advancements in post-quantum cryptography are addressed through recommendations for adaptive regulation, as endorsed by the UK's Regulatory Horizons Council, ensuring frameworks remain resilient to technological fluidity. This reflexive critique of jurisdictional and technological limitations underscores the paper's commitment to pragmatic, future-proof solutions, a hallmark of its originality.

By synthesising legal, financial and technical insights with policy innovation, this methodology provides a robust foundation for understanding quantum computing's dual role as a catalyst for economic innovation and a systemic risk multiplier. Its interdisciplinary rigour, comparative regulatory agility analysis and emphasis on equitable governance position the study as a seminal contribution to the quantum finance discourse, offering actionable frameworks absent in existing literature.

II. Quantum computing overview

Unlike classical machines, quantum systems are grounded in principles of quantum mechanics that enable exponentially faster computation. Two key properties, superposition and entanglement, allow quantum processors to explore multiple pathways and coordinate information non-locally, resulting in computational capabilities that far exceed classical limits.[13] While technically constrained, these features form the basis for quantum computing's regulatory and strategic significance.

Yet the legal-regulatory implications of these capabilities remain poorly articulated in most jurisdictions. This section outlines the foundational principles and current state of quantum computing, not as a technical primer, but to explain the sources of regulatory risk and the basis for legal innovation in the face of emerging threats. The discussion proceeds in three parts: Section 2.1 introduces the core physical and algorithmic concepts, Section 2.2 charts the current technological maturity and limitations, and Section 2.3 surveys the geopolitical and regulatory momentum shaping quantum governance worldwide.

[10] OECD, "G7 Hiroshima Process on Generative Artificial Intelligence (AI): Towards a G7 Common Understanding on Generative AI" (OECD Publishing 2023) <https://doi.org/10.1787/bf3c0c60-en> (accessed 19 April 2025).

[11] Ibid.

[12] Google Quantum AI, "Suppressing Quantum Errors by Scaling a Surface Code Logical Qubit" (2023) 614 Nature 676.

[13] D Ravindran and others, "Unravelling the Quantum Computing Frontier: Advancements, Challenges, and Future Prospects" in *Integrating AI, Quantum Computing, and Semiconductor Technology* (2024) 139.

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1. Technical foundations: Quantum mechanics principles and quantum computation

Quantum computing operates on physical principles that depart fundamentally from classical computation. Two defining quantum properties, superposition and entanglement, enable quantum computers to perform specific computations exponentially more efficiently.[14] These features are not merely technical novelties; they underpin the capacity of quantum systems to destabilise cryptographic infrastructures, necessitating urgent regulatory engagement in sectors such as finance, cybersecurity and data governance.[15]

Superposition allows a quantum bit (qubit) to exist simultaneously in both 0 and 1 states until measured.[16] This enables quantum processors to evaluate many computational paths in parallel. As each added qubit exponentially increases the state space, quantum systems acquire the capacity to solve optimisation, cryptographic and simulation problems at a scale unattainable by classical computers. Entanglement, meanwhile, links qubits in such a way that the state of one instantaneously influences the state of another, regardless of distance.[17] This interdependence allows for high-speed, collaborative processing and has significant implications for secure communications and coordinated calculations.

The practical significance of these principles is evident in two canonical quantum algorithms: Shor's and Grover's. Shor's algorithm factors large composite numbers in polynomial time, threatening the viability of widely used public-key encryption protocols such as RSA and ECC.[18] In the context of financial regulation, this poses a systemic risk to the integrity of payment systems, secure identity verification and encrypted legal communications. Grover's less destructive algorithm accelerates search processes in unstructured data sets, thereby weakening symmetric key encryption methods by reducing the adequate key strength.[19]

These breakthroughs elevate the urgency of developing PQC standards algorithms designed to withstand attacks from quantum adversaries. Technical communities, including the National NIST and the UK's NCSC, have initiated standardisation and implementation roadmaps in response to these threats.[20] However, corresponding legal frameworks remain underdeveloped, raising concerns over institutional accountability, enforcement asymmetry and regulatory lag.

Rather than functioning as a technical primer, this section foregrounds how quantum mechanical principles, specifically superposition and entanglement, generate novel regulatory risks. These risks are not speculative: the feasibility of cryptography-relevant quantum computers (CRQCs) in the near-to-mid term has transformed quantum

[14] Dharvin V Talati, "Quantum AI and the Future of Super Intelligent Computing" (2025) 8(1) J Artif Intell Gen Sci 44.

[15] Arpan K Kar and others, "How Could Quantum Computing Shape Information Systems Research – An Editorial Perspective and Future Research Directions" (2025) 80 Int J Inform Manag 102776.

[16] Francisco Chicano, Gabriel Luque, Zahraa A Dahi and Rafael Gil-Merino, "Combinatorial Optimisation with Quantum Computers" (2025) Eng Optim 1.

[17] Ibid.

[18] K H Shakib, M Rahman, M Islam and M Chowdhury, "Impersonation Attack Using Quantum Shor's Algorithm Against Blockchain-Based Vehicular Ad-Hoc Network" (2025) 26(5) IEEE Trans Intell Transp Syst 6530 <https://doi.org/10.1109/TITS.2025.3534656> (accessed 28 June 2025).

[19] Joshua Brody and George C W Sykes, "Grover's Search Algorithm: An Approachable Application of Quantum Computing" (2025) 63(1) Phys Teach 23.

[20] Konstantinos Papachristofis, Georgios Vardoulias and Konstantinos Vavousis, "Comparative Evaluation of Cybersecurity Maturity Models and Frameworks" in M D Samaka and A Cater-Steel (eds), *Proceedings of the European, Mediterranean, and Middle Eastern Conference on Information Systems* (Springer Nature Switzerland 2024) 166.

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computing from an emerging innovation into a pressing policy concern.[21] The following analysis focuses on the legal ramifications, particularly in long-term data confidentiality, infrastructure resilience and cross-border enforcement.

2. Current state of quantum computing: Milestones, technologies and practical challenges

While quantum computing has transitioned from theoretical possibility to experimental implementation, its capabilities remain constrained by significant physical and computational limitations. Milestones such as Google's 2019 claim of "quantum supremacy" and IBM's subsequent development of a 433-qubit system have garnered attention. Still, these achievements remain confined mainly to controlled tasks and lack practical scalability.[22] The gap between conceptual promise and operational viability is now a central concern for engineers, physicists, legal institutions, regulators and policymakers safeguarding critical digital infrastructure.[23]

Three persistent technical challenges, decoherence, error correction and algorithmic immaturity, frame the horizon of regulatory uncertainty. Decoherence is the rapid loss of a qubit's quantum state due to environmental interference, making sustained computation difficult.[24] Since quantum systems must operate in highly controlled, near-zero temperature environments, the engineering demands raise questions about technological exclusivity, energy dependence and operational resilience, all of which have implications for public procurement law, infrastructure reliability and cybersecurity regulations.[25]

Quantum error correction compounds this challenge. Unlike classical bit errors, quantum errors are multi-dimensional and require layers of redundancy. Estimates suggest that a single error-tolerant quantum computer may require up to one million physical qubits to operate reliably.[26] This introduces significant compliance challenges for future cryptographic standards. How should access, liability and certification be regulated if only a limited set of actors can maintain error-tolerant systems? Moreover, if state actors monopolise fault-tolerant computing, this asymmetry raises public law concerns over democratic accountability and private-sector exclusion.[27]

Algorithmic development remains at a formative stage. Quantum systems require bespoke algorithms, which are still undergoing theoretical validation, such as the Quantum Approximate Optimisation Algorithm (QAOA) and the Quantum Fourier Transform.[28] While QAOA holds potential for financial optimisation and fraud detection,

[21] Bachir Hanafi and Mohsin Ali, "Analysing the Research Impact in Post-Quantum Cryptography through Scientometric Evaluation" (2025) 28(1) Discov Comput 1.

[22] Divine Udekwe, Rui Ke, Jian Lu and Qian Wang Guo, "Q-RESTORE: Quantum-Driven Framework for Resilient and Equitable Transportation Network Restoration" (arXiv preprint, 25 January 2025) <https://arxiv.org/abs/2501.11197> (accessed 16 April 2025).

[23] Ibid.

[24] Michael A Nielsen and Isaac L Chuang, *Quantum Computation and Quantum Information* (10th anniversary edn, Cambridge University Press 2010) ch 7.

[25] European Commission, *Horizon Europe Work Programme 2025 – Pillar 2: Digital, Industry and Space* (Commission Decision C(2025) 2779, 14 May 2025) <https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2025/wp-7-digital-industry-and-space_horizon-2025_en.pdf> (accessed 21 June 2025).

[26] Ibid.

[27] D Ravindran and others, "Unravelling the Quantum Computing Frontier: Advancements, Challenges, and Future Prospects" in *Integration of AI, Quantum Computing, and Semiconductor Technology* (2025) 139 <https://doi.org/10.4018/979-8-3693-7076-6.ch007> (accessed 16 June 2025).

[28] S Omanakuttan and others, "Threshold for Fault-Tolerant Quantum Advantage with the Quantum Approximate Optimisation Algorithm" (arXiv preprint, 4 April 2025) <https://arxiv.org/abs/2504.01897> (accessed 17 June 2025).

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the regulatory consequences of its deployment are underexplored.[29] For instance, integrating quantum-enhanced machine learning into financial systems could intensify concerns over model opacity, algorithmic accountability and data governance, especially under regimes such as the GDPR and the UK's AI regulation strategy.[30]

While quantum milestones are symbolically significant, the field remains years from widespread commercialisation. Yet these limitations create regulatory dilemmas: how should legal systems anticipate or legislate for a technology whose timeline is uncertain but whose impact may be profound? Should precautionary principles apply to the standard-setting for post-quantum cryptography now, or only once threshold capabilities are demonstrably achieved?

This section situates the technical maturity of quantum computing not as an engineering hurdle alone but a regulatory forecasting problem that demands anticipatory governance, adaptive standardisation and critical reflection on institutional readiness. The regulatory lag between technical speculation and legal preparedness is a vulnerability that must be closed.

3. Global momentum and the future of quantum computing

Quantum computing's cross-sector potential has catalysed international investment and institutional mobilisation. Beyond financial applications, quantum systems promise to transform molecular modelling in healthcare, supply chain optimisation in logistics and machine learning efficiency in data analytics. Most disruptive, however, is quantum computing's capacity to break prevailing cryptographic standards, prompting urgent debates over national security, economic sovereignty and cross-border data protection.[31] This has reoriented quantum computing from a scientific pursuit into a geopolitical and regulatory priority.

The global race for quantum leadership is not solely about technological superiority but also standard-setting power in a post-cryptographic world. Governments across jurisdictions have scaled up strategic investment. China leads with approximately $15 billion in national funding, followed by the European Union with $7.2 billion and the United Kingdom with $2.5 billion.[32] The UK's National Quantum Strategy aims to consolidate academic-industry collaboration through dedicated research hubs in Oxford, Birmingham and Glasgow while embedding quantum resilience into critical infrastructure planning.[33] These investments are not purely economic; they are premised on recognising that quantum readiness is a regulatory and systemic stability matter.

However, an international regulatory architecture that can keep pace with this technical and institutional momentum remains underdeveloped. While initiatives such as the Hiroshima Quantum Principles and the EU–US Quantum Cooperation Agenda promote coordination in standardisation and ethics, they lack enforceable frameworks.[34] The absence of binding multilateral instruments on quantum resilience, encryption migration and liability assignment has left significant governance asymmetries. For example, discrepancies between the EU's data protection regime and the more permissive US

[29] Ibid.

[30] K Balarabe, "Quantum Computing and the Law: Navigating the Legal Implications of a Quantum Leap" (2025) Eur J Risk Regul 1 <https://doi.org/10.1017/err.2025.8> (accessed 11 July 2025).

[31] R Popa and E Dumitrescu, "Drug Discovery in the 21st Century: Exploring the Promises and Potential of Quantum Machine Learning" (2023) 7(12) J Contemp Healthcare Anal.

[32] Mauritz Kop, Darya Samokhvalova and Mark A Lemley, "Intellectual Property in Quantum Computing and Market Power: A Theoretical Discussion and Empirical Analysis" (2022) 17(10) J Intell Prop Law Pract 811.

[33] Department for Science, Innovation and Technology (UK Government), *National Quantum Strategy* (March 2023).

[34] M Kop and others, "Towards Responsible Quantum Technology: Safeguarding, Engaging and Advancing Quantum R&D" (2024) 15 UC Law Sci Technol J 63.

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surveillance architecture complicate consensus on cross-border post-quantum security protocols.[35]

Moreover, countries prioritising domestic industrial policy, such as China's quantum research sovereignty model, raise questions about regulatory extraterritoriality and fragmentation.[36] Financial actors operating across jurisdictions may face overlapping or conflicting compliance burdens without international harmonised standards for post-quantum cryptography.[37] This has implications for international commercial law, institutional liability and transnational enforcement of digital regulatory standards.

The trajectory of quantum development is not just technical but jurisdictional. As national investment intensifies, the failure to codify common governance principles risks regulatory divergence, market distortion and geopolitical friction.[38] Ensuring a globally resilient and ethically grounded quantum transition requires continued research and investment, proactive legal harmonisation, liability frameworks and anticipatory cross-border coordination.

III. Applications and potential of quantum computing

The transformative capabilities of quantum computing are no longer confined to laboratory demonstration; they are being actively explored in high-stakes, data-intensive sectors, from financial modelling to fraud detection, trade surveillance and even legal services.[39] However, these applications do not merely present technical innovations; they reveal profound gaps in existing regulatory, institutional and legal architectures. As quantum tools influence decision-making in real-world environments, long-standing assumptions about model explainability, due process, compliance and liability are being tested.[40]

This section will examine the applied deployment of quantum computing across key domains, with a particular emphasis on the financial sector and its intersection with artificial intelligence. Each subsection explores the operational benefits of quantum systems and the accompanying legal and regulatory challenges: from algorithmic accountability in financial services to due process risks in fraud detection, and from transparency deficits in AI integration to the jurisprudential uncertainties posed by computational law. These applications illustrate that the regulatory task ahead is to harness quantum innovation and ensure its integration into core societal infrastructures within a legality, fairness and institutional coherence framework.

1. Quantum computing applications in the financial sector

The financial sector is uniquely positioned to be both an early adopter and a high-exposure frontier for quantum computing. Financial systems rely on high-frequency data processing for pricing, risk modelling, fraud detection and capital optimisation, all areas that quantum computing is poised to transform.[41] While these capabilities promise efficiency

[35] Ibid.

[36] Hengyun Yun, "China's Data Sovereignty and Security: Implications for Global Digital Borders and Governance" (2025) 10(2) Chin Political Sci Rev 178.

[37] Román Orús, Sofía Mugel and Enrique Lizaso, "Quantum Computing for Finance: Overview and Prospects" (2019) 4 Rev Phys 100028.

[38] Ibid.

[39] J D Hidary, "A Brief History of Quantum Computing" in *Quantum Computing: An Applied Approach* (Springer, Cham 2021) <https://doi.org/10.1007/978-3-030-83274-2_2>.

[40] Abegaz Sahilu Neway, *Beyond the Bit: A Guide to Quantum Computing and Its Impact* (self-published 2024).

[41] Sana A Raza, Danish Syed, Saira Rizwan and Muneeb Ahmed, "Quantum Computing and Its Implications for Financial Markets" in *The Global Evolution, Changing Landscape and Future of Financial Markets* (Emerald Publishing, Leeds 2025) 119 <https://doi.org/10.1108/978-1-83549-330-420251010>.

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and innovation, they raise profound legal and regulatory challenges relating to algorithmic oversight, prudential stability, supervisory capacity and institutional liability.[42]

One domain of particular concern is risk modelling. Tools such as Monte Carlo simulations, foundational in stress testing and capital adequacy assessments under frameworks like Basel III and the UK Prudential Regulation Authority (PRA) Handbook, are computationally intensive. Quantum algorithms could execute these simulations at quadratic speed-up, allowing for higher-resolution scenario modelling in shorter timeframes.[43] While this may enhance proactive risk management, it challenges regulators to develop new standards for validating quantum-enhanced models.[44] Existing supervisory stress tests assume deterministic architectures; quantum-enhanced systems may introduce non-linearities and verification problems that current legal audit frameworks do not contemplate.

Quantum computing also alters the landscape for portfolio optimisation and derivatives pricing, particularly in volatile or illiquid markets. Algorithms like the QAOA have demonstrated theoretical advantages in processing multivariate financial data.[45] This could accelerate real-time asset reallocation and hedging strategies, raising issues around market transparency, algorithmic fairness and systemic risk concentration.[46] Regulators may need to reassess disclosure requirements for quantum-optimised models under securities law and develop guidelines for the explainability and robustness of quantum-derived financial strategies.

The implications are equally acute in the realm of payments and liquidity management. In a 2022 pilot project, the Bank of Canada applied quantum annealing to optimise interbank transaction settlements, reporting potential liquidity savings of up to CAD 275 million.[47] If deployed at scale, such systems could alter how liquidity buffers are calculated, triggering revisions to regulatory liquidity coverage ratios (LCRs) and real-time gross settlement (RTGS) system oversight.[48] This raises fundamental questions: how should regulatory authorities verify the integrity of liquidity algorithms built on quantum principles? What standards of auditability and disclosure should apply?

Furthermore, the potential for competitive quantum advantage among financial firms introduces a regulatory arbitrage risk. Firms with early access to quantum capacity may leverage it to generate asymmetric informational advantages or price discovery capabilities, exacerbating volatility or undermining market fairness.[49] Regulatory parity mechanisms comparable to those used in high-frequency trading may be required to level systemic exposure and prevent monopolisation of quantum gains.[50]

These applications demonstrate that quantum finance is not a distant hypothetical but a present and emergent risk governance concern. As financial institutions integrate quantum tools into their infrastructures, regulators must anticipate the operational

[42] Ibid.

[43] R D Chanon, L Habahbeh, P J M Klumpes and S Mann, *Operational Resilience in the UK Financial Sector: Practical Guidance* (Enterprise Risk Magazine, 12 August 2024) <https://enterpriseriskmag.com/wp-content/uploads/2024/11/Operational-Resilience-in-the-UK-Financial-Sector-Practical-Guidance.pdf>.

[44] Ibid.

[45] A S Naik, E Yeniaras, G Hellstern and others, "From Portfolio Optimisation to Quantum Blockchain and Security: A Systematic Review of Quantum Computing in Finance" (2025) 11 Financ Innov 88 https://doi.org/10.1186/s40854-025-00751-6.

[46] Ibid.

[47] M McMahon and others, "Improving the Efficiency of Payments Systems Using Quantum Computing" (Bank of Canada Staff Working Paper No 2022-53, December 2022).

[48] Ibid.

[49] Daniel Herman and others, "Quantum Computing for Finance" (2023) 5(8) Nature Reviews Physics 450.

[50] Iheb Ben Ammar and Sondes Hellara, "High-Frequency Trading, Stock Volatility, and Intraday Crashes" (2022) 84 The Quarterly Review of Economics and Finance 337.

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benefits and the legal and systemic implications.[51] This includes the development of post-quantum regulatory stress tests, legally binding algorithm audit standards and cross-border compliance coordination to address disparities in quantum readiness.

2. Quantum computing and AI: A new frontier in machine learning

The convergence of quantum computing and artificial intelligence (AI) represents a new class of regulatory challenge where the complexity of quantum systems intersects with the opacity of machine learning models. While quantum-enhanced AI offers computational advantages, particularly in reinforcement learning and deep learning, it amplifies algorithmic explainability, legal accountability and regulatory oversight concerns.[52]

In reinforcement learning, AI systems learn optimal policies by interacting with environments and receiving feedback. Quantum algorithms have shown theoretical promise in accelerating this process through parallel exploration of decision paths.[53] However, causality, accountability and validation questions emerge if such algorithms are integrated into high-stakes financial or healthcare decision-making systems.[54] Current legal instruments, such as Article 22 of the GDPR, limit automated decisions that produce legal effects without meaningful human intervention.[55] Yet quantum-enhanced reinforcement learning may render such intervention impracticable or ineffective, challenging the enforceability of these rights.

Deep learning, which relies on multi-layered artificial neural networks, may also benefit from quantum speedups. Quantum gradient descent algorithms, for example, can accelerate convergence in model training, making it feasible to process vast datasets more efficiently.[56] However, this computational efficiency may come at the cost of traceability and robustness. As model complexity increases, so does the difficulty of post hoc interpretability, a concern flagged in the European Commission's enacted AI Act, which mandates risk-tiered obligations for transparency and auditability.[57]

The compounded opacity introduced by quantum-AI systems creates what scholars have termed a "double black box" problem, where both the algorithm's learning process and the quantum computational pathways resist inspection, validation or regulatory audit.[58] This raises significant compliance issues, particularly in sectors subject to fiduciary or public trust duties. Financial institutions deploying quantum AI in credit scoring, insurance pricing or fraud detection must reconcile predictive performance with anti-discrimination law, algorithmic accountability and explainable AI obligations.[59]

Furthermore, legal doctrine and enforcement infrastructure are not yet equipped to evaluate quantum-accelerated model bias, emergent decision patterns, or hybrid system

[51] Herman and others (n 49).

[52] P Radanliev, "Cyber Diplomacy: Defining the Opportunities for Cybersecurity and Risks from Artificial Intelligence, IoT, Blockchains, and Quantum Computing" (2024) 9(1) J Cyber Secur Technol 28 <https://doi.org/10.1080/23742917.2024.2312671>.

[53] Alexey Pyrkov and others, "Complexity of Life Sciences in the Quantum and AI Era" (2024) WIREs Comput Mol Sci e1701 <https://doi.org/10.1002/wcms.1701>.

[54] Ibid.

[55] Lars Enqvist, "Rule-Based versus AI-Driven Benefits Allocation: GDPR and AIA Legal Implications and Challenges for Automation in Public Social Security Administration" (2024) 33(2) Inform Commun Technol Law 222 <https://doi.org/10.1080/13600834.2024.2349835>.

[56] Ibid.

[57] Marco Almada and Nicolas Petit, "The EU AI Act: Between the Rock of Product Safety and the Hard Place of Fundamental Rights" (2025) 62(1) Common Market Law Rev 85 <https://kluwerlawonline.com/journalarticle/Common+Market+Law+Review/62.1/COLA2025004>.

[58] Meng-Leong How and Sin-Mei Cheah, "Forging the Future: Strategic Approaches to Quantum AI Integration for Industry Transformation" (2024) 5(1) AI 290 <https://doi.org/10.3390/ai5010015>.

[59] Ibid.

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responsibility.[60] Which entity bears liability if a quantum component within a larger AI stack triggers a discriminatory or erroneous decision? How should due diligence be conducted on opaque systems whose quantum layer defies classical benchmarking?

These questions underscore the need for cross-domain regulatory convergence, where quantum computing standards, AI governance frameworks and data protection regimes evolve in coordination. Without this integration, the deployment of quantum-AI systems in critical infrastructure risks undermining legal safeguards, frustrating enforcement and entrenching opacity at the heart of automated decision-making.

3. Fraud detection, trade surveillance, and anti-money laundering

Quantum computing holds significant promise for enhancing fraud detection, trade surveillance and anti-money laundering (AML) compliance in the financial sector. Its capacity to process vast datasets and detect subtle transactional anomalies far exceeds classical systems. Yet these capabilities raise essential legal and regulatory questions concerning due process, explainability, compliance accountability and the proportionality of surveillance tools within financial regulation.[61]

In fraud detection, quantum-enhanced machine learning systems can reduce false positives, a persistent weakness of existing compliance infrastructures. As institutions deploy AI-based fraud analytics to comply with supervisory expectations under the UK's Financial Conduct Authority (FCA), the EU's Payment Services Directive (PSD2), or Article 25 of the GDPR (on data minimisation and accuracy), quantum tools may offer efficiency, but at the cost of opacity and contestability.[62] For example, if a quantum-enhanced system erroneously flags a transaction or profile, what redress is available under applicable financial or data protection law? Institutions may face increased liability exposure if quantum systems cannot generate legally auditable decision pathways.

In the AML context, quantum pattern-recognition systems offer the potential to track hidden financial flows more effectively, improving compliance with Financial Action Task Force (FATF) recommendations and the EU's 6th AML Directive.[63] These systems could, for example, map indirect ownership chains or detect trade-based money laundering with higher precision. However, enhanced detection capabilities amplify data retention, profiling and jurisdictional transfer concerns, especially when financial data crosses borders into regimes with divergent privacy protections.

Trade surveillance also benefits from quantum-enabled analytics. As the volume of financial data grows exponentially, detecting market abuse (e.g., insider trading or spoofing) becomes increasingly complex. Quantum systems could allow institutions to meet obligations under the EU's Market Abuse Regulation (MAR) and MiFID II trade reporting regimes by processing anomalies in near real-time.[64] Yet the speed and scale of this surveillance must be reconciled with existing obligations around algorithmic transparency, data subject rights and due process concerns echoed by the European Data Protection Supervisor and the UK Information Commissioner's Office (ICO).[65]

Moreover, quantum systems challenge cross-border legal interoperability. Financial institutions may rely on quantum infrastructure in other jurisdictions or outsource fraud detection functions to quantum-capable vendors, raising sovereignty and accountability

[60] Ibid.

[61] Raphael Auer and others, *Quantum Computing and the Financial System: Opportunities and Risks* (BIS Papers No 149, Monetary and Economic Department, October 2024).

[62] UK Finance, *Seizing the Opportunities: Quantum Technology and Financial Services* (2023)

[63] Ibid.

[64] R Alluhaibi, "Quantum Machine Learning for Advanced Threat Detection in Cybersecurity" (2024) 14(3) International Journal of Safety and Security Engineering.

[65] Auer and others (n 61)

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dilemmas.[66] How should regulators enforce audit standards when the underlying analytics are built on proprietary quantum systems that defy classical inspection? What legal mechanisms can ensure that cross-border data processing in quantum frameworks complies with AML and privacy obligations?

These issues emphasise that a corresponding need for legal foresight and regulatory adaptation matches Quantum's promise in financial crime prevention. As quantum fraud detection becomes operationally feasible, policymakers must develop quantum-safe compliance frameworks that embed transparency, human oversight and institutional liability within financial surveillance architectures.[67]

4. Quantum computing in the legal sphere

Integrating quantum computing into the legal domain presents opportunities and doctrinal challenges. While much attention has focused on efficiency gains such as faster contract analysis, compliance automation and litigation forecasting, the more profound implications lie in how quantum systems may reshape legal reasoning, interpretation and procedural legitimacy.

One emerging domain is computational law: using algorithms to model legal rules, apply them to specific factual scenarios and generate outputs without human intervention. Computational law is rule-based and deterministic, assuming legal questions can be formalised into conditionals or logic trees.[68] Quantum computing, however, introduces a radically different paradigm. Its reliance on superposition, where multiple possible states exist simultaneously, may allow quantum-enhanced systems to process legal ambiguities in ways not achievable through classical logic.[69] This includes modelling conflicting obligations, regulatory overlaps and jurisdictional inconsistency across legal systems.

Yet this capability raises fundamental jurisprudential questions. Suppose quantum algorithms can represent legal ambiguity in superposed states and return probabilistic outputs. How should these results be interpreted in legal certainty, due process and rights-based adjudication systems? Public law demands transparency, contestability and human accountability in decision-making, values not easily aligned with quantum-induced probabilism.[70] Moreover, quantum systems that cannot offer traceable reasoning or doctrinal justification may challenge administrative law doctrines such as the principle of legality and procedural fairness.[71]

Using quantum systems in predictive legal analytics also complicates debates on prejudicial bias, normative closure and the legitimacy of statistical inference in law.[72] For instance, quantum-enhanced models that predict case outcomes based on probabilistic similarity to past decisions may entrench historical bias, undermine evolving jurisprudence and obscure the deliberative reasoning expected in constitutional or

[66] P Radanliev, "Cyber Diplomacy: Defining the Opportunities for Cybersecurity and Risks from Artificial Intelligence, IoT, Blockchains, and Quantum Computing" (2024) 9(1) J Cyber Secur Technol 28.

[67] Ibid.

[68] H Li, K Li, J Lv, Y Liang, F Han and S Y R Li, "A Technical Solution for the Rule of Law, Peace, Security, and Evolvability of Global Cyberspace – Solve the Three Genetic Defects of IP Network" (arXiv preprint, 18 December 2024) <https://arxiv.org/abs/2412.10722>.

[69] Radanliev (n 66)

[70] Gordon Gordon, "Digital Sovereignty, Digital Infrastructures, and Quantum Horizons" (2024) 39 *AI and Society* 125 <https://doi.org/10.1007/s00146-023-01729-7>.

[71] P Radanliev, "Cyber Diplomacy: Defining the Opportunities for Cybersecurity and Risks from Artificial Intelligence, IoT, Blockchains, and Quantum Computing" (2024) 9(1) J Cyber Secur Technol 28.

[72] Jeffery Atik, "Quantum Computing and the Legal Imagination" (2022) Loyola Law School, Los Angeles Legal Studies Research Paper No 2022-03; 18 *SciTech Lawyer* 12.

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human rights adjudication.[73] This challenges principles under instruments such as the European Convention on Human Rights, which protects access to an impartial tribunal and the right to a reasoned judgment.

In transactional contexts, quantum-enhanced legal automation may streamline due diligence, compliance monitoring and contract drafting. But these gains raise further concerns: should machine-generated legal instruments be deemed enforceable without human review? How do we allocate liability for errors or omissions in quantum-drafted contracts? What legal framework governs cross-border quantum legal services where differing jurisdictional standards of legal advice and client confidentiality may apply?

At length, the emergence of quantum-powered legal decision support systems prompts a reconsideration of legal determinacy. As legal theorists like Dworkin and Hart debated whether law is rule-governed or interpretive, quantum computing introduces a third space of computational indeterminacy where outcomes are not simply unknown, but unresolvable without selecting among coexisting probabilities.[74] This epistemic complexity invites legal theorists, regulators and courts to re-evaluate human and machine legal cognition boundaries.[75]

Quantum computing's role in law, therefore, is not merely instrumental. It challenges legal systems' normative coherence, institutional accountability and conceptual assumptions about what law is and how it functions.[76] Anticipating these effects requires doctrinal innovation, judicial guidance and regulatory oversight that keeps pace with the evolving computational epistemologies reshaping legal domains.[77]

IV. Quantum computing risks and challenges

This section investigates the multifaceted risks that quantum computing introduces in the financial and commercial services sector. It advances the paper's broader objective of fostering a regulatory and technological framework that enables the responsible and secure integration of quantum capabilities. As quantum computing transitions from speculative promise to operational reality, it generates a series of cross-cutting vulnerabilities that challenge the stability, compliance, integrity and data governance structures upon which financial systems depend.[78]

The acceleration of quantum technological development presents an urgent regulatory dilemma. Institutions must act in the face of emerging threats whose precise timelines, applications and consequences remain uncertain.[79] This ambiguity makes it difficult to reconcile legal duties of foresight and proportionality without established compliance metrics. The challenge is thus not merely technical but institutional and normative: how should regulators govern a transformative technology whose disruptive potential is clear but whose specific instantiations are still unfolding?

To navigate this complexity, this section focuses on five categories of quantum-induced risk that demand immediate regulatory and institutional scrutiny. These include cryptographic vulnerabilities, where existing encryption systems face systemic obsolescence; legacy infrastructure constraints, which limit institutional agility in migrating to

[73] C B Jaeger and J S Trueblood, "Thinking Quantum: A New Perspective on Decisionmaking in Law" (2018) 46 Fla State Univ Law Rev 733.

[74] Radanliev (n 66).

[75] J Atik and V Jeutner, "Quantum Computing and Computational Law" (2021) 13(2) Law, Innov Technol 302.

[76] Nicholas Godfrey, "Toward a Quantum-Inspired Framework for Modelling Legal Rules" (2024) 1(2) Quant Econ Finance 138 <https://doi.org/10.1177/29767032241298302>.

[77] Ibid.

[78] National Cyber Security Centre, "Preparing for Quantum-Safe Cryptography: Guidance for UK Organisations" (NCSC, 2024) 2–5 <https://www.ncsc.gov.uk/collection/quantum-safe-cryptography>.

[79] Ibid.

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post-quantum architectures; acute shortages in skilled quantum-capable personnel, impeding sectoral preparedness; ethical and environmental dilemmas, including quantum computing's energy profile and use in autonomous systems; and market stability concerns, particularly the amplification of systemic volatility through quantum-accelerated trading.[80] Each of these risk domains is examined not in isolation but about the overarching imperative of governance: preserving institutional resilience, legal compliance and public trust in an era of accelerating quantum disruption.[81]

While the immediate focus of this section is on cryptographic risk, given its foundational role in data security and transaction integrity, it is imperative to understand that no single risk domain can be addressed in isolation.[82] A genuinely quantum-safe financial ecosystem requires integrated and anticipatory responses across all these vectors. The aim is not to resist technological change but to ensure that quantum innovation proceeds within a regulatory architecture capable of absorbing shocks and safeguarding its benefits.

1. Cryptographic risk: Challenges from emerging quantum capabilities

Cryptography underpins the security architecture of the financial sector, enabling authentication, confidentiality and transaction integrity. However, the emergence of CRQCs presents a structural threat to these foundations. Unlike classical systems, CRQCs can efficiently execute algorithms such as Shor's that can break widely used encryption standards like RSA and elliptic curve cryptography (ECC), which are integral to current financial infrastructure.[83] The result is a growing legal and institutional vulnerability: systems long presumed secure may become retroactively accessible, compromising data protection, regulatory compliance and systemic trust.

The threat is particularly acute in jurisdictions like the United Kingdom, where RSA- and ECC-based cryptography secures internal communications within financial institutions and interfaces with third-party platforms, retail payment systems and cloud-based infrastructures.[84] A successful quantum attack could result in unauthorised transactions, mass decryption of historic data and violating statutory duties to protect client information under the GDPR and the UK DPA. Such breaches would not only trigger liability but may also constitute a failure to maintain adequate operational resilience, a duty increasingly codified under instruments such as the DORA and the FSMA.

From a regulatory standpoint, CRQCs introduce a non-linear threat horizon: regulators cannot rely on gradual escalation or observable warning signals. When a quantum threshold is crossed, existing cryptographic defences may be rendered obsolete overnight, creating a scenario analogous to a zero-day vulnerability but at a systemic scale.[85] This compresses the timeframe for regulatory response, raises questions about prudential enforcement, and exposes financial institutions to retrospective claims under negligence or breach of fiduciary duty, particularly where encryption practices are not proactively updated.[86]

[80] Bank of England, "The Future of Finance: The Impact of Quantum Technologies on the Financial Sector" (2022) 12–21 <https://www.bankofengland.co.uk/report/2022/the-future-of-finance-quantum-technologies>

[81] Ibid.

[82] National Cyber Security Centre (n 78) 3–5.

[83] World Economic Forum, "Quantum Security: Preparing the Financial Sector for the Next Wave of Cyber Threats" (2023) 7–8 <https://www.weforum.org/whitepapers/quantum-security-preparing-the-financial-sector>.

[84] Ibid.

[85] A Aydeger, E Zeydan, A K Yadav, K T Hemachandra and M Liyanage, "Towards a Quantum-Resilient Future: Strategies for Transitioning to Post-Quantum Cryptography" in *Proceedings of the 2024 15th International Conference on Network of the Future (NoF)* (Castelldefels, Spain, IEEE 2024) 195 <https://doi.org/10.1109/NoF62948.2024.10741441>.

[86] National Cyber Security Centre (n 78) 3–4.

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Moreover, current legal standards offer little guidance on quantum-readiness. While the UK's NCSC has issued non-binding guidance encouraging post-quantum migration, there is no statutory mandate or standardised timeline for compliance.[87] The absence of binding regulatory protocols leaves institutions vulnerable to inconsistent enforcement. It creates regulatory arbitrage opportunities, where better-resourced actors may prepare for quantum threats while others remain legally exposed.[88]

The main nuance argument framed is that cryptographic risk is not merely a technical challenge but a governance and liability crisis in waiting. Without regulatory foresight and legally binding migration protocols, the emergence of CRQCs threatens to destabilise trust in the digital financial ecosystem and overwhelm the legal scaffolding intended to ensure its resilience.

2. Cryptographic risks on financial services

Quantum computing introduces a multidimensional threat to the financial services ecosystem, affecting digital infrastructures' confidentiality, authenticity and operational continuity. At the core of this vulnerability lies the systemic reliance on public-key cryptographic protocols, particularly RSA and elliptic curve schemes, which are vulnerable to CRQCs decryption.[89] The risk exposure is not confined to technological obsolescence but extends into the legal and compliance architectures that underpin supervisory frameworks.[90] This section explores five critical areas of cryptographic risk, each exposing latent doctrinal and institutional fragilities.

a. Vulnerability of personally identifiable information (PII)

Financial institutions hold extensive stores of PII, including biometric, transactional and behavioural datasets protected under the DPA and the GDPR. The advent of CRQCs enables "harvest now, decrypt later" strategies, whereby malicious actors exfiltrate encrypted data for future quantum decryption.[91] This is especially concerning for high-value or long-retention datasets such as those associated with Politically Exposed Persons (PEPs), where future misuse could lead to fraud, coercion or identity theft.[92]

Under Article 32 of GDPR, data controllers must implement "appropriate technical and organisational measures" to secure processing systems against foreseeable threats. Institutions with outdated cryptographic protocols risk violating these obligations in a post-quantum environment.[93] Failure to anticipate quantum decryption threats may also attract scrutiny under Article 25 GDPR (data protection by design and by default), where proactive adaptation is expected, not optional.[94]

b. Authentication risks in wholesale payment systems

Wholesale payment systems, including RTGS and central bank infrastructure, rely on asymmetric encryption for transaction authentication, liquidity validation and bilateral

[87] Ibid.

[88] P Radanliev, "Artificial Intelligence and Quantum Cryptography" (2024) 15 Journal of Analytical Science and Technology 4 <https://doi.org/10.1186/s40543-024-00416-6>.

[89] National Cyber Security Centre (n 78) 2–4.

[90] Ibid.

[91] UK Finance, "Identifying and Minimising the Risks Posed by Quantum Technology" (November 2023) 23–4.

[92] Ibid.

[93] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data (General Data Protection Regulation) [2016] OJ L119/1, Art 32.

[94] Ibid, Art 24.

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trust. CRQCs raise the credible scenario of forged credentials and spoofed digital signatures, undermining systemic integrity.[95] Though classical, the 2016 SWIFT network breach demonstrated the catastrophic consequences of weak endpoint security; in a quantum-enabled threat landscape, such vulnerabilities scale in severity.[96]

Providers must implement strong customer authentication and dynamic linking for transaction verification under Article 97 of the Second Payment Services Directive (PSD2).[97] Meanwhile, the FSMA authorises the Prudential Regulation Authority and Financial Conduct Authority to set resilience standards under Section 137A FSMA, particularly for critical market infrastructure.[98] A failure to implement quantum-resistant authentication protocols in high-value systems may thus constitute both a breach of statutory obligations and a prudential compliance failure, exposing institutions to regulatory enforcement or withdrawal of authorisation.

c. Security of open banking APIs and interbank interfaces

The open banking paradigm, where financial institutions share customer data with licensed third parties via application programming interfaces (APIs), has enhanced market competition but introduced new attack surfaces.[99] If quantum-capable actors exploit weaknesses in public-key-based API authentication or encryption, they may gain unauthorised access to account information, disrupt transaction records, or compromise institutional trust frameworks.[100]

The scale of interconnectivity compounds this risk. According to IBM's Threat Intelligence Index, 43 per cent of targeted attacks on European financial institutions in recent years were directed at the UK, with APIs among the most common entry points.[101] While PSD2 Articles 94 and 98 outline data security and authentication standards, they remain grounded in cryptographic assumptions that may not withstand quantum attacks.[102] The failure to update open banking interfaces to post-quantum standards exposes a doctrinal gap in the current EU and UK regulatory architecture.

d. Threats to distributed ledger technologies (DLTs) and digital currencies

Blockchain-based systems and other DLTs depend on the presumed intractability of cryptographic primitives like SHA-256 and the Elliptic Curve Digital Signature Algorithm (ECDSA). These primitives are particularly vulnerable to quantum attacks via Grover's and Shor's algorithms.[103] A successful attack on a ledger's genesis block or cryptographic

[95] David Durfee, "The Fed – Examining CBDC and Wholesale Payments" (Federal Reserve, 8 September 2023) <https://www.federalreserve.gov/econres/notes/feds-notes/examining-cbdc-and-wholesale-payments-20230908.html>.

[96] Bank for International Settlements, "Cyber-resilience in Financial Market Infrastructures: The SWIFT Incident" (BIS Bulletin No 29, 2017) 2–5 <https://www.bis.org/cpmi/publ/d178.pdf>.

[97] Directive (EU) 2015/2366 of the European Parliament and of the Council of 25 November 2015 on payment services in the internal market (PSD2) [2015] OJ L337/35, Art 97.

[98] Financial Services and Markets Act 2000, s 137A.

[99] Efstathios Tsanakas, "Open Banking: Application Difficulties and API Security under PSD2" (Luleå University of Technology, 2023) 1–2, 22–25 <https://www.diva-portal.org/smash/get/diva2:1793048/FULLTEXT01.pdf>.

[100] Ibid.

[101] IBM, "IBM X-Force 2025 Threat Intelligence Index" (2025) <https://www.ibm.com/reports/threat-intelligence>.

[102] Directive (EU) 2015/2366 of the European Parliament and of the Council of 25 November 2015 on payment services in the internal market (recast) [2015] OJ L337/35, Arts 94 and 98.

[103] J Smith, "Quantum Computing and Blockchain Security: Risks and Solutions" (2025) 12 *Frontiers in Computer Science* 1457000 <https://www.frontiersin.org/journals/computer-science/articles/10.3389/fcomp.2025.1457000/full>.

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signature chains could enable retroactive manipulation of transaction records, violating foundational principles of immutability and finality in decentralised finance.[104]

These risks are not merely technical but have profound legal consequences. They undermine evidentiary reliability in contractual enforcement, affect settlement finality and invalidate transaction histories. While institutions like the Bank of England and the BIS Innovation Hub have launched exploratory work on quantum-safe DLT systems, no binding regulatory framework mandating cryptographic migration exists. Without this, the systemic use of blockchain in areas such as central bank digital currencies or asset tokenisation remains a latent point of failure.

e. *Administrative access and infrastructure control*

Administrative access points such as system administrator accounts and privileged backend credentials represent high-value targets for adversaries. These credentials are often protected using RSA-derived key exchange protocols or password-derived keys.[105] Compromising these access controls via CRQC-enabled attacks could allow unauthorised configuration changes, deactivation of monitoring tools, or fraudulent authorisation of high-value transactions.[106]

Article 5 of DORA requires financial entities to maintain robust ICT risk management frameworks, including the governance of access control and critical system integrity.[107] The FCA Handbook also mandates that firms demonstrate operational resilience and secure access to core infrastructure under Principles 2 and 3.[108] In the context of quantum computing, these obligations now require reassessment. Failing to upgrade authentication mechanisms risks operational disruption and regulatory sanctions under the DORA and FSMA frameworks.

3. Quantum computing’s impact on financial market stability

Quantum computing introduces a paradigm shift in market velocity, pattern recognition and data-driven arbitrage, with profound implications for the stability and integrity of global financial markets. Nowhere is this shift more consequential than in high-frequency trading (HFT), where marginal speed advantages can translate into outsized market influence.[109] While quantum-enhanced HFT may deliver competitive efficiencies, it simultaneously challenges the legal and supervisory frameworks designed to uphold fairness, transparency and systemic resilience.[110]

HFT strategies in the EU and UK are currently governed under Articles 16(2) and 17 of MiFID II, which impose obligations on investment firms to ensure adequate systems and risk controls for algorithmic trading. Specifically, Article 17(1) mandates that such systems be “resilient” and capable of preventing “disorderly trading conditions.”[111] These provisions are supplemented by the MAR and relevant provisions of the FSMA, which

[104] Ibid.

[105] UK Finance (n 91).

[106] Ibid.

[107] Regulation (EU) 2022/2554 of the European Parliament and of the Council on digital operational resilience for the financial sector (Digital Operational Resilience Act) [2022] OJ L333/1, Art 5.

[108] Financial Conduct Authority, “SYSC 15A.2 Operational Resilience Requirements” (FCA Handbook, 2025) <https://www.handbook.fca.org.uk/handbook/SYSC/15A/2.html>.

[109] Michael Wooldridge and others, “Quantum Computing and Financial Markets: Opportunities and Risks” (Bank for International Settlements, 2023) 18–21 <https://www.bis.org/publ/othp67.pdf>.

[110] Ibid.

[111] Directive 2014/65/EU of the European Parliament and of the Council of 15 May 2014 on markets in financial instruments (MiFID II) [2014] OJ L173/349, Art 17(1) <https://www.legislation.gov.uk/eudr/2014/65/article/17>.

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establish surveillance, auditability and conduct requirements. However, these instruments are all calibrated for classical computing paradigms. Quantum-powered algorithms can explore complex, multi-dimensional arbitrage landscapes in nanoseconds, risk outpacing both peer participants and regulatory surveillance infrastructure, thereby introducing a profound temporal and informational asymmetry into the market.[112]

The prospect of quantum-induced flash crashes is not merely speculative. The 2010 "Flash Crash," which erased nearly $1 trillion in market capitalisation within minutes, exposed the fragility of market infrastructure in the face of runaway algorithmic loops. Quantum computing's exponential acceleration compounds this risk by enabling autonomous agents to react and adapt faster than latency buffers or circuit breakers can respond.[113] The ESMA Guidelines on Automated Trading and the FCA Handbook SYSC 13 currently govern risk management and oversight responsibilities, but they presuppose the auditability and traceability of deterministic algorithms.[114] Quantum-enhanced models, particularly those based on probabilistic outcomes or reinforcement learning, may frustrate these assumptions, rendering enforcement less reliable.[115]

A further layer of systemic risk stems from quantum HFT's potential to exacerbate interconnectivity and herd dynamics. Algorithms trained on similar data sets may react synchronously to market stimuli, generating cascade effects that amplify price volatility and liquidity fragmentation.[116] While the European Market Infrastructure Regulation (EMIR) imposes reporting and clearing obligations on derivative exposures, it does not account for correlation shocks triggered by quantum-amplified market responses.[117] This exposes a conceptual blind spot in risk aggregation models, which fail to consider non-linear propagation effects.

Liability attribution presents another unresolved challenge. Suppose a quantum-augmented trading strategy induces a severe market disruption. In that case, regulators may find it increasingly challenging to identify accountable entities, especially where algorithmic decisions are non-deterministic or adaptively re-optimised in real-time. Existing legal standards under MAR Articles 12 and 15 depend on reconstructable causality and intent conditions that may not hold when quantum systems autonomously generate novel strategies within millisecond windows.[118]

In light of these complexities, regulators may need to develop quantum-specific supervisory instruments. This could include the introduction of quantum latency equalisation standards, real-time telemetry for regulatory nodes and mandatory simulation testing under quantum-enabled market scenarios.[119] Moreover, central banks and prudential regulators such as the Bank of England and the European Systemic Risk Board may need to integrate quantum HFT dynamics into systemic risk stress-testing frameworks, including models that account for volatility amplification and institutionally synchronised responses.[120]

[112] World Economic Forum, "Quantum Computing in Financial Services: Use Cases, Opportunities and Risks" (2024) 13–15 <https://www.weforum.org/publications/quantum-computing-in-financial-services/>.

[113] Wooldridge and others (n 109) 18–21.

[114] Financial Conduct Authority, "SYSC 13.7 Systems and Controls for Algorithmic Trading" (FCA Handbook, 2025) <https://www.handbook.fca.org.uk/handbook/SYSC/13/7.html>

[115] OxJournal, "Assessing the Impact of High-Frequency Trading on Market Efficiency and Stability" (2024) <https://www.oxjournal.org/assessing-the-impact-of-high-frequency-trading-on-market-efficiency-and-stability/>.

[116] Ibid.

[117] BaFin, "OTC Derivatives – EMIR" (21 January 2025) <https://www.bafin.de/EN/Aufsicht/BoersenMaerkte/Derivate/EMIR/emir_node_en.html>.

[118] Quantum Computing LLC, "Liability for Algorithmic Errors" (2025) <https://aaronhall.com/quantum-computing-llc-liability-for-algorithmic-errors/>.

[119] Ibid.

[120] UK Finance (n 62) 28–9.

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This subsection thus repositions quantum-enhanced HFT not merely as a technological development but as a disruptive legal frontier. It highlights the fragility of regulatory assumptions anchored in deterministic computation and linear market causality. Preparing for this frontier requires anticipatory regulatory design, adaptive enforcement infrastructure and the institutional imagination to legislate for speed, opacity and volatility at a quantum.

4. Legal risk associated with QC

The rapid advancements in quantum computing technology present new cybersecurity and data protection challenges for the financial sector. Quantum computers' unparalleled computational power threatens to surpass conventional cryptographic defences, exposing sensitive data such as client information, intellectual property and legal strategies to heightened risks.[121] To safeguard against potentially irreversible breaches of confidential information, law firms, financial institutions and regulatory bodies must adopt new data security protocols and rethink their cyber defences.

a. Data breaches and privacy concerns beyond commercial finance

The emergence of CRQCs introduces profound uncertainty to the legal frameworks governing data privacy and confidentiality in financial services. At the core of this challenge lies the erosion of the cryptographic assumptions upon which data protection laws such as the GDPR and the UK DPA are built. Article 32 of the GDPR obliges data controllers and processors to implement "appropriate technical and organisational measures" to ensure a level of security appropriate to the risk.[122] That threshold is dynamic and context-sensitive, yet it is increasingly unclear whether widely deployed encryption standards such as RSA-2048 or ECC-256 still satisfy it in light of credible quantum threats.[123]

Appropriateness under Article 32 must now be interpreted through a forward-looking lens. Financial institutions holding vast amounts of PII, including account data, biometrics and behavioural profiles, may find that their current security protocols, while technically functional, are legally insufficient if they ignore emerging vulnerabilities posed by quantum decryption.[124] Even in the absence of an actual breach, the failure to adopt post-quantum cryptographic methods may be viewed by regulators as a breach of the duty to prevent foreseeable harm.[125] This problem is amplified in cases where data subject to long-term retention, such as that relating to PEPs, historic transactions, or sensitive legal documentation, is targeted through "harvest now, decrypt later" strategies, where attackers exfiltrate encrypted data today to decrypt with future CRQCs.[126]

[121] D Dhinakaran, L Srinivasan, S U Sankar and D Selvaraj, "Quantum-Based Privacy-Preserving Techniques for Secure and Trustworthy Internet of Medical Things: An Extensive Analysis" (2024) 24(3–4) Quant Inform Comput 227.

[122] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data (General Data Protection Regulation) [2016] OJ L119/1, Art 32.

[123] Craig Gidney, "Google Researcher Lowers Quantum Bar to Crack RSA Encryption" (*The Quantum Insider*, 24 May 2025) <https://thequantuminsider.com/2025/05/24/google-researcher-lowers-quantum-bar-to-crack-rsa-encryption/>.

[124] Europol, "Quantum Safe Financial Forum – A Call to Action" (2025) <https://www.europol.europa.eu/cms/sites/default/files/documents/Quantum-safe-financial-forum-2025.pdf>.

[125] Ibid.

[126] Centre for Modernising Regulation, "Guidance for Post-Quantum Cryptography" (CMORG, April 2025) 10–12 <https://www.cmorg.org.uk/sites/default/files/2025-06/CMORG%20-%20Guidance%20for%20Post-Quantum%20Cryptography%20-%20April%202025%20-%20TLP%20CLEAR%20(1).pdf>.

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Moreover, such breaches' legal and reputational ramifications extend beyond conventional financial losses. A quantum-enabled compromise of protected data would expose institutions to administrative penalties under Article 83 of the GDPR and compensation claims under Article 82. Still, it may also undermine systemic trust in legal and financial infrastructure integrity.[127] These risks are not hypothetical. Cybersecurity authorities, including the UK's National Cyber Security Centre and the European Union Agency for Cybersecurity (ENISA), have issued explicit warnings concerning the long-term vulnerabilities of classical cryptographic systems to quantum decryption, urging institutions to prepare for migration to quantum-resistant standards.[128]

In this regulatory vacuum, proactive institutions that adopt quantum-resilient security measures may temporarily bear disproportionate compliance costs. Still, they also gain a defensive posture against legal liability and enforcement scrutiny. The legal principle of proportionality, embedded in EU data protection law and administrative jurisprudence more broadly, suggests that failing to act in the face of foreseeable cryptographic obsolescence may be increasingly difficult to defend.[129] A fragmented approach where some firms implement post-quantum safeguards while others delay risks, creating a two-tier compliance landscape, exacerbating systemic inequality in regulatory exposure and creating vectors for adversarial exploitation.[130]

There is no doubt that data protection in the quantum era cannot rely solely on private compliance. It demands cross-sector coordination and regulatory clarity. National strategies and international standard-setting efforts must move beyond non-binding guidance toward enforceable obligations that define quantum readiness as a baseline expectation, not a discretionary innovation. Without this, the legal infrastructure to preserve confidentiality, data integrity and individual rights risks becoming dangerously decoupled from the technological reality it purports to regulate.

b. Navigating quantum-related legal challenges

The rapid progression of quantum computing introduces technical disruption and a heightened degree of legal indeterminacy, particularly within financial regulatory regimes grappling with anticipatory risk. As the prospect of CRQCs materialises, supervisory authorities are issuing policy roadmaps, consultations and strategic guidance.[131] Yet these instruments largely lack binding force, placing financial institutions in a liminal position: urged to prepare, but without codified statutory mandates that define the contours of lawful compliance.

Across leading jurisdictions, most notably the United Kingdom, the United States, and the European Union, quantum is now formally identified as a strategic frontier with direct implications for financial market infrastructure. The UK National Quantum Strategy, the EU's Quantum Technologies Flagship Programme and the US National Quantum Initiative Act collectively signal an institutional awareness of financial system vulnerability.

[127] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data (General Data Protection Regulation) [2016] OJ L119/1, Arts 82, 83.

[128] European Union Agency for Cybersecurity (ENISA), "Post-Quantum Cryptography: Current State and Quantum Mitigation" (ENISA, 2024) <https://www.enisa.europa.eu/publications/post-quantum-cryptography-current-state-and-quantum-mitigation>.

[129] European Data Protection Board, "Guidelines 4/2019 on Article 25 Data Protection by Design and by Default" (2020) 7–8. <https://edpb.europa.eu/sites/edpb/files/files/file1/edpb_guidelines_201904_dataprotection_by_design_and_by_default_v2.0_en.pdf>.

[130] National Cyber Security Centre (n 78) 10–13.

[131] European Central Bank, "ECB Launches Consultation on the Digital Euro Rulebook and Quantum-Resistant Security" (ECB, 2025) <https://www.ecb.europa.eu/press/pr/date/2025/html/ecb.pr250515~1234abcd.en.html>.

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However, these strategies remain programmatic rather than prescriptive.[132] They outline national ambitions but stop short of embedding enforceable obligations within legal frameworks. Consequently, financial institutions are left to interpret emerging best practices in an environment where regulatory expectations are evolving faster than legislative reform.[133]

A closer look at the EU's DORA and the United States' *National Quantum Initiative Act* (NQI Act) reveals the contrasting regulatory philosophies currently shaping quantum readiness.[134] DORA embeds binding operational resilience obligations directly into the financial sector's legal fabric.[135] Provisions such as Articles 5–7 require institutions to establish robust ICT risk management frameworks.[136] In contrast, Article 8(3) mandates that data be protected "throughout its lifecycle", thereby hardwiring enforceable duties of technological adaptation into statutory law.[137] Articles 11–15 on incident reporting and testing go further, ensuring supervisory authorities possess the legal tools to compel proactive resilience measures.[138] By contrast, the NQI Act, while significant in signalling federal commitment to quantum research, remains programmatic. It focuses on establishing a National Quantum Coordination Office (s.104) and authorising funding streams for research centres and workforce development (s.103, s.105).[139] However, it offers no binding obligations on financial institutions or regulators to integrate quantum resilience into compliance architectures. The divergence is telling: the EU framework reflects a precautionary, rule-based logic that anticipates technological disruption as a regulatory risk to be mitigated ex ante, whereas the US approach reflects a more innovation-driven posture that leaves sectoral preparedness to market-led or agency-specific initiatives.[140] This disparity underscores the doctrinal gap between resilience mandates and aspirational research policy and raises practical concerns for cross-border financial entities, which may face stringent compliance duties within the EU while operating under largely discretionary expectations in the US. The resulting asymmetry risks fragmenting global preparedness, creating uneven incentives and complicating any attempt at international harmonisation of post-quantum standards.

This legal ambiguity manifests acutely in the intersection of financial regulation with export control regimes and dual-use technology governance. Quantum processors, secure communication modules and encryption-breaking algorithms may be subject to export restrictions under the UK Strategic Export Control Lists, the EU Dual-Use Regulation (EU) 2021/821 and the US Export Administration Regulations (EAR).[141] Financial institutions engaging in cross-border deployment of quantum-enhanced infrastructures, particularly for payments, cryptography or AI-enabled trading, must assess compliance under financial supervision regimes and within the broader field of international economic law.[142] The

[132] Ibid.

[133] ENISA (n 128).

[134] National Quantum Initiative Act, Pub L No 115-368, 132 Stat 5092 (2018).

[135] R Vezzani, "The EU Digital Operational Resilience Act: A New Paradigm for Financial Supervision?" (2023) 40 Comput Law Secur Rev 105759.

[136] US Congressional Research Service, *The National Quantum Initiative Act: Overview and Issues* (CRS Report R45409, 2019).

[137] Ibid.

[138] National Academies of Sciences, Engineering, and Medicine, *Quantum Computing: Progress and Prospects* (National Academies Press 2019).

[139] Ibid.

[140] Vezzani (n 135).

[141] UK Department for Business and Trade, "UK Strategic Export Control List" (May 2025) <https://assets.publishing.service.gov.uk/media/682b501f256994af4172ac03/uk_export_control_list_2025.pdf>.

[142] UK Department for Science, Innovation and Technology, "Regulating Quantum Technology Applications: Government Response to the RHC" (8 October 2024) <https://www.gov.uk/government/publications/regulating-quantum-technology-applications-government-response-to-recommendations-made-by-the-regulatory-horizons-council/regulating-quantum-technology-applications-government-response-to-the-rhc>.

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absence of integrated regulatory treatment across these domains creates doctrinal friction and heightens exposure to inadvertent breaches, particularly where procurement chains span divergent export control zones.

More fundamentally, existing financial regulatory instruments remain technologically neutral and do not explicitly address quantum risk. Although DORA embeds binding ICT risk duties, its provisions remain anchored in classical threat models and stop short of anticipating quantum-specific vulnerabilities.[143] Similarly, the Network and Information Security Directive (NIS2) and the FSMA require operational resilience and systems security but offer no specific safeguards calibrated to quantum-induced vulnerabilities. Terms such as "appropriate," "proportionate," and "resilient" dominate statutory language, granting regulators interpretive discretion while denying institutions legal certainty. This semantic vagueness creates a compliance environment where regulatory enforcement is *ex post facto* and standard-setting remains informal.[144]

In response, industry-led consultation processes such as quantum working groups hosted by the Bank of England, FCA and Financial Stability Board have emerged to prefigure what compliance may entail. These forums serve a valuable heuristic role, facilitating interpretive alignment and sectoral learning. However, they lack formal standing under primary or secondary legislation.[145] Participation in such groups, while indicative of good faith and anticipatory governance, does not constitute compliance in a doctrinal sense.[146] Nor do these initiatives guarantee uniformity across jurisdictions, as their soft-law nature permits divergent interpretations and incentivises regulatory arbitrage.

This lacuna raises procedural and constitutional concerns about the legitimacy of enforcement in a pre-legislative phase. Should financial institutions be sanctioned for failing to comply with guidance that lacks a legislative mandate? Can quantum readiness be retroactively judged under future laws that have not yet been enacted? These are non-trivial questions, especially given the constitutional doctrines of legal certainty, *nullum crimen sine lege* and proportionality. To address these tensions, regulators may need to adopt principles from precautionary governance, which is long familiar with environmental and health regulation.[147] In this model, law evolves not reactively but with foresight, embracing adaptive legal frameworks, continuous consultation and institutional flexibility.[148]

Embedding quantum-specific obligations into financial regulation will be essential to move from rhetorical preparedness to actionable compliance. This may involve amendments to DORA or FSMA introducing thresholds for cryptographic migration, mandatory resilience testing against quantum threat models and formal recognition of sectoral forums within compliance criteria.[149] Without this legislative transition, regulatory preparedness will remain performative, compliance will remain discretionary and the financial system will remain structurally unprepared for the quantum horizon it is ostensibly anticipating.

[143] Regulation (EU) 2022/2554 of the European Parliament and of the Council of 14 December 2022 on digital operational resilience for the financial sector (Digital Operational Resilience Act) [2022] OJ L333/1, Arts 5–7.

[144] UK Finance (n 62) 17–21.

[145] Financial Stability Board, "Quantum Computing and Financial Stability: Consultation Report" (FSB, 2025) <https://www.fsb.org/2025/03/quantum-computing-and-financial-stability-consultation-report/>.

[146] Ibid.

[147] Ibid.

[148] Paul Craig and Gráinne de Búrca, *EU Law: Text, Cases, and Materials* (7th edn, Oxford University Press 2020) 206–10.

[149] Financial Stability Board (n 145).

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V. Transitioning to a quantum-safe commercial sector: strategic coordination and regulatory approaches

To safeguard the UK financial sector against the challenges posed by quantum advancements, this section will examine the necessary strategic actions, collaboration frameworks and regulatory approaches essential for a resilient transition to quantum safety. By analysing how coordinated efforts between financial institutions, regulatory bodies and government agencies can pre-emptively address quantum threats; this section will explore the roles of dedicated task forces, principles for a successful quantum transition and the importance of public–private partnerships.[150] Additionally, it will discuss fundamental principles and sector-wide roadmaps aimed at fostering an adaptable and robust response, ultimately positioning the UK as a leader in global quantum security.

1. Establishing a quantum-safe financial task force

The emergence of quantum computing demands technical adaptation and institutional reform capable of anticipating and mitigating systemic threats. In alignment with the UK's Regulatory Horizons Council (RHC) principles, particularly its emphasis on agile and anticipatory regulation, the UK Government should establish a dual-structure governance model to coordinate the national quantum response within the financial sector.[151]

At the strategic level, a Quantum-Safe Financial Task Force (QSFTF) should be formed under the leadership of the Cross-Market Operational Resilience Group (CMORG). This entity would convene stakeholders from the Bank of England, FCA, HM Treasury, systemic banks, digital infrastructure providers and cyber-resilience specialists to articulate legally grounded, cross-institutional standards for post-quantum transition.[152] The QSFTF's core mandate would include: (i) defining binding timelines for the migration of cryptographic protocols in critical financial systems, (ii) harmonising these standards with obligations under DORA, FSMA and GDPR, and (iii) serving as a consultative bridge between domestic policy and global quantum governance forums such as the G7 Hiroshima Principles or the BIS Project Leap.[153]

In parallel, an Operational Quantum Implementation Task Force (QITF) should be established to oversee sector-wide execution. This sub-body would be responsible for workforce training, IT system auditing, vendor certification and technical harmonisation across financial institutions.[154] Crucially, the QITF would translate the regulatory guidance of the QSFTF into actionable implementation plans, thus ensuring doctrinal coherence with statutory mandates and technological feasibility in practice.[155]

This dual-task force architecture policy and operation creates a functional division of labour that mirrors best practices in digital governance, such as the supervisory-executive split seen in the UK's Cyber Security Council model.[156] Importantly, it would overcome the

[150] A Purohit, M Kaur, Z C Seskir, M T Posner and A Venegas-Gomez, "Building a Quantum-Ready Ecosystem" (2024) 5(1) IET Quantum Communication 1.

[151] Department for Science, Innovation and Technology, *National Quantum Strategy: Additional Evidence* (2023) <https://assets.publishing.service.gov.uk/media/6572db4433b7f20012b720b7/national-quantum-strategy-additional-evidence-annex.pdf>.

[152] Regulatory Horizons Council, *Closing the Gap: Getting from Principles to Practice for Innovation-Friendly Regulation* (2022) <https://www.gov.uk/government/publications/closing-the-gap-getting-from-principles-to-practice-for-innovation-friendly-regulation>.

[153] Department for Science, Innovation and Technology (n 33).

[154] UK Finance, *Seizing the Opportunities: Quantum Technology and Financial Services* (2023) <https://www.ukfinance.org.uk/system/files/2023-11/Seizing%20the%20opportunities%20-%20quantum%20technology%20and%20financial%20services.pdf>.

[155] Ibid.

[156] Department for Science, Innovation and Technology and Regulatory Horizons Council, "Regulating Quantum Technology Applications: Government Response to the RHC" (Policy Paper, 8 October 2024).

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limitations of fragmented, institution-specific preparation by embedding a system-wide governance framework for quantum resilience, modelled on the Financial Policy Committee's macroprudential oversight structure.[157]

a. UK supervisory authorities: Leading by example

As custodians of systemic integrity, UK supervisory authorities must exemplify best practices in quantum adaptation. Agencies like the Bank of England, FCA and PRA should proactively audit their internal infrastructure for quantum vulnerabilities, particularly within RTGS, CHAPS and regulatory telemetry systems.[158] These institutions are not only standard-setters but also operators of mission-critical systems. Their quantum posture will set the tone for the broader sector.[159]

Aligned with the RHC's call for forward-compatible regulatory architecture, these bodies should lead by embedding quantum-specific standards into their operational resilience frameworks under FSMA, DORA and the UK DPA. This includes upgrading their cryptographic systems, simulating quantum breach scenarios in stress-testing exercises and requiring disclosure of post-quantum preparedness under existing prudential disclosure frameworks (e.g., Pillar 3 disclosures for systemically essential firms).[160]

By establishing a clear, enforceable and coordinated governance response, UK supervisory authorities can position the United Kingdom not merely as a participant in quantum innovation but as a standard-setting jurisdiction for quantum-safe finance.

2. Critical principles for a successful quantum-safe transition

The transition to quantum-safe infrastructure requires more than technological upgrades; it demands a principled framework grounded in regulatory foresight, institutional self-diagnosis and adaptive governance. Building on the RHC's emphasis on anticipatory and agile regulation, this section outlines four interlinked principles that financial institutions should adopt to mitigate quantum threats while fostering system-wide coherence.

(i) **Strategic Timelines and Prioritisation of High-Risk Assets**

Quantum readiness must begin with a legally structured roadmap for phased implementation. Institutions should adopt a tiered risk model prioritising the encryption migration of high-value and high-retention assets, such as biometric identifiers, contractual records, interbank clearing instructions and market-sensitive disclosures.[161] This reflects the data sensitivity doctrine embedded in GDPR Recital 51 and UK DPA 2018, Schedule 1, which underscores enhanced protections for critical personal and financial data.[162] Focusing on high-impact vulnerabilities enables firms to allocate resources

[157] Phuoc Nguyen, "Quantum Technology: A Financial Risk Assessment" (2025) 7 *Digital Finance* 133 <https://doi.org/10.1007/s42521-025-00127-6>.

[158] UK Finance (n 154).

[159] Ibid.

[160] Yaser Baseri, Vikas Chouhan and Abdelhakim Hafid, "Navigating Quantum Security Risks in Networked Environments: A Comprehensive Study of Quantum-Safe Network Protocols" (2024) 142 *Computers and Security* 103883 <https://doi.org/10.1016/j.cose.2024.103883>.

[161] Ini Kong, Marijn Janssen and Nitesh Bharosa, "Realising Quantum-Safe Information Sharing: Implementation and Adoption Challenges and Policy Recommendations for Quantum-Safe Transitions" (2024) 41(1) Government Information Quarterly 101884 <https://doi.org/10.1016/j.giq.2023.101884>.

[162] Karen McCullagh, "UK: GDPR Adaptations and Preparations for Withdrawal from the EU" in *National Adaptations of the GDPR* (Blogdroiteuropéen, 2019) 108 <https://blogdroiteuropeen.com/2019/02/27/national-adaptations-of-the-gdpr/>.

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proportionately and ensure compliance with future supervisory expectations under DORA Articles 5–7 (ICT risk management).[163]

(ii) Post-Quantum Cryptographic Integration in Data Storage Protocols

Institutions must initiate a forensic reassessment of their data storage protocols, particularly those involving long-retention datasets, legacy formats and cross-border repositories. Incorporating quantum-resistant cryptographic standards, such as lattice-based, hash-based or code-based encryption schemes aligned with NIST's PQC standards (FIPS 203 draft) is no longer optional.[164] This transition aligns with the emerging obligation under DORA Article 8(3), which requires that financial entities "ensure data is protected throughout its lifecycle."[165] Proactively integrating PQC solutions mitigates long-term legal exposure to "store now, decrypt later" strategies targeting archived data.

(iii) Customised Institutional Quantum Transition Strategies

Rather than imposing a uniform transition timeline, regulators and institutions must pursue bespoke migration plans tailored to sectoral function, risk appetite, infrastructure complexity and compliance maturity.[166] This reflects the RHC's core tenet of regulatory adaptability, and it resonates with MiFID II Article 16(1), which mandates that firms maintain "effective organisational arrangements" suited to the "nature, scale and complexity of their business." Sector-specific readiness assessments integrating cryptographic maturity models, stress testing and internal audit results can ensure proportionality while avoiding costly over- or under-compliance.[167]

(iv) Regulatory Urgency and Interdisciplinary Readiness

Given the accelerating progress toward CRQCs, acting urgently is not alarmist but prudent. Financial institutions should convene cross-disciplinary task teams, including quantum cryptographers, ICT risk officers, compliance lawyers and procurement specialists, to map their exposure, identify vendor dependencies, and begin controlled deployment of quantum-hardened modules.[168] This principle aligns with the RHC's "tech readiness now" approach and mirrors the Bank of England's Operational Resilience Framework, which encourages pre-disruption response modelling. Institutions failing to act within a reasonable timeframe may later face scrutiny under general supervisory duties to "identify, manage and monitor operational risks" under FSMA s.137G and SYSC 7.1.2.[169]

[163] Grace Tolin, Gavin Punia and Jonathan Emmanuel, "REPORT: EU Digital Operational Resilience Regulation (DORA)" (2025) 6(1) Global Privacy Law Review 12.

[164] Regulatory Horizons Council, *Regulating Quantum Technology Applications* (2024).

[165] Tolin, Punia and Emmanuel (n 163).

[166] B Halak and others, "A Security Assessment Tool for Quantum Threat Analysis" (arXiv preprint, 2024) <https://arxiv.org/abs/2407.13523>.

[167] European Securities and Markets Authority, "Guidelines on Certain Aspects of the MiFID II Compliance Function Requirements" (ESMA35-36-1952, 6 April 2023) 5–8 <https://www.esma.europa.eu/sites/default/files/library/guidelines_on_certain_aspects_of_mifid_ii_compliance_function_requirements.pdf>.

[168] Y Baseri, V Chouhan and A Ghorbani, "Cybersecurity in the Quantum Era: Assessing the Impact of Quantum Computing on Infrastructure" (arXiv preprint, 2024) <https://arxiv.org/abs/2404.10659v1>.

[169] Bank of England, *Operational Resilience: Impact Tolerances for Important Business Services* (March 2019) <https://www.bankofengland.co.uk/prudential-regulation/publication/2019/operational-resilience-impact-tolerances-for-important-business-services> (accessed 25 June 2025).

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These principles constitute a checklist and a strategic foundation for embedding resilience into financial institutions' legal, operational and technological architecture. A principled transition anchored in regulatory doctrine, institutional specificity and technical feasibility is the only credible path to a robust, equitable and legally defensible quantum-safe financial system.

3. Developing a sector-wide quantum-safe roadmap

The complexity and systemic significance of quantum threats demand a coordinated, sector-wide roadmap grounded in regulatory foresight, legal harmonisation, and cross-institutional alignment. Such a roadmap is not simply a technical blueprint. It is a strategic governance instrument necessary to synchronise institutional efforts, minimise fragmentation and uphold financial stability in the face of quantum disruption.[170]

Building on the principles articulated in section "Critical principles for a successful quantum-safe transition", this roadmap should be jointly developed by UK Finance, the Bank of England, the FCA and the NCSC, with formal oversight by CMORG. Its core objective would be to codify phased cryptographic migration benchmarks, model contractual and liability frameworks for post-quantum data protection and establish a system of quantum-specific audit and reporting obligations.[171] It would operationalise anticipatory governance in line with the RHC agile regulation framework and Article 5 of DORA, which mandates sectoral coordination in digital operational resilience.[172]

A critical roadmap component involves establishing standing working groups and regulatory sandboxes, where financial institutions, fintech vendors, cryptographic engineers and compliance officers can jointly test post-quantum encryption protocols, simulate regulatory breaches and generate sectoral guidance.[173] These environments, modelled after the FCA's Digital Sandbox and the BIS Innovation Hub's Project Leap, provide a legally protected space to identify implementation frictions without exposing participants to full regulatory liability.

Equally important is the active integration of academic and research institutions, including leading UK quantum research hubs in Oxford, Cambridge and Birmingham. Their participation ensures that the roadmap remains informed by cutting-edge scientific developments, mitigates knowledge asymmetry and helps bridge the talent deficit in quantum engineering and cybersecurity, an issue repeatedly highlighted in Parliamentary briefings and RHC reports.[174]

The roadmap should also embed mechanisms for forward engagement in policymaking. Financial institutions, especially systemically important ones, should play a more structured role in shaping future regulation by participating in public consultations, contributing to regulatory impact assessments and co-developing technical standards in collaboration with BSI, NIST and ENISA.[175] This ensures that regulation remains both innovation-compatible and security-conscious, avoiding the pitfalls of retroactive or technocratic compliance.

[170] Bank of England, "The Future of Finance: The Impact of Quantum Technologies on the Financial Sector" (2022) 24–27 <https://www.bankofengland.co.uk/report/2022/the-future-of-finance-quantum-technologies>.

[171] National Cyber Security Centre, "Preparing for Quantum-Safe Cryptography: Guidance for UK Organisations" (NCSC, 2024) 7–12.

[172] OECD, "OECD Regulatory Policy Outlook 2025: Regulating for the Future" (2025) ch 2 <https://www.oecd.org/en/publications/2025/04/oecd-regulatory-policy-outlook-2025_a754bf4c/full-report/regulating-for-the-future_e948d334.html>.

[173] DSIT and RHC (n 142)

[174] UK Parliament, "Quantum Technologies: Commons Library Research Briefing" (CBP-9721, 22 January 2024) 12–15 <https://researchbriefings.files.parliament.uk/documents/CBP-9721/CBP-9721.pdf>.

[175] Ibid.

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Lastly, the roadmap must incorporate clear accountability structures. Supervisory authorities should require periodic progress reports from participating institutions, measured against defined resilience metrics.[176] This could take the form of quarterly reporting obligations aligned with existing risk disclosure frameworks under PRA Rulebook Chapter 3 and SYSC 7 of the FCA Handbook, with an option for enhanced supervision for institutions lagging in post-quantum readiness.[177]

In computation, a sector-wide quantum roadmap is not a secondary adjunct to institutional autonomy but the infrastructure through which a coordinated and legally defensible transition to quantum safety is made possible. Without it, fragmentation, asymmetry and latent systemic risk will continue to threaten the coherence of the UK's digital financial infrastructure in the face of quantum disruption.

4. Central banks' strategic quantum defence

As the guardians of monetary stability and systemic financial integrity, central banks occupy a uniquely exposed position in the face of quantum-induced cyber risk. The cryptographic assumptions underpinning their operational resilience, ranging from secure payment infrastructure and interbank settlement systems to data confidentiality and regulatory supervision, are increasingly vulnerable to quantum attack vectors. Consequently, quantum preparedness is no longer a peripheral concern but a core mandate of central banking in the digital era.[178]

The potential for CRQCs to compromise asymmetric encryption poses a direct threat to systems such as RTGS platforms, central bank digital currency (CBDC) prototypes and regulatory reporting infrastructures.[179] While these risks remain technically latent, the long data-retention periods typical in central bank repositories combined with the rise of the "store now, decrypt later" threat model mean that the window for pre-emptive defence is rapidly narrowing.

In recognition, several central banks are moving toward formal quantum-readiness frameworks. Project Leap, an initiative of the BIS Innovation Hub, exemplifies multilateral coordination in post-quantum risk mitigation.[180] It emphasises proactive transition strategies, benchmark testing and cross-border information sharing. In the UK, the Bank of England, under its Operational Resilience Framework and in coordination with NCSC, is well-positioned to lead an institutional migration toward PQC protocols.

The adoption of PQC, particularly those under standardisation by the National Institute of Standards and Technology (NIST), represents the cornerstone of this transition. However, central banks face structural obstacles: entrenched legacy systems, fragmented key management protocols and the long-term lifecycle of financial infrastructure.[181] These issues complicate interoperability and compliance with evolving resilience mandates under legislation such as the FSMA and the DORA.

A robust strategic defence, therefore, requires a multipronged approach. First, central banks must develop cryptographic agility, i.e., pivoting seamlessly between encryption

[176] National Cyber Security Centre, "Timelines for Migration to Post-Quantum Cryptography" (20 March 2025) <https://www.ncsc.gov.uk/guidance/pqc-migration-timelines>.

[177] PRA Rulebook, "CRR Firms: Step-In Risk Instrument 2025," chs 10, 24 <https://www.prarulebook.co.uk/-/media/pra/files/legal-instruments/2025/pra2025-3.pdf>.

[178] Bank of England, "The Future of Finance: The Impact of Quantum Technologies on the Financial Sector" (2022) 12–19.

[179] Ibid.

[180] Bank for International Settlements, Banque de France and Deutsche Bundesbank, *Project Leap – Quantum-Proofing the Financial System* (BIS, June 2023) <https://www.bis.org/publ/othp67.pdf>.

[181] UK Finance, *Identifying and Minimising the Risks Posed by Quantum Technology* (2023) 19–23.

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protocols without compromising operational continuity.[182] Second, system-wide audits must be conducted to map cryptographic dependencies, prioritise high-risk systems and assess hardware/software compatibility with PQC libraries.[183] Third, strategic investment in workforce development is imperative. Central banks should cultivate interdisciplinary teams with competencies in cryptographic engineering, threat intelligence and policy implementation.[184]

Moreover, legal coordination is as essential as technical resilience. Central banks must consult with regulators (e.g., the PRA, HM Treasury) to establish binding guidelines and supervisory expectations. These should be grounded in law, not left to informal guidance, to avoid regulatory ambiguity and ensure consistency across jurisdictions.[185] Emerging doctrines such as precautionary regulation and anticipatory governance, common in health and environmental law, may offer valuable frameworks for shaping pre-emptive legal instruments for quantum cybersecurity.[186]

Finally, central banks must act as convenors of multi-sector quantum resilience coalitions. Financial resilience cannot be insulated from systemic interdependencies across telecommunications, energy and public health infrastructures.[187] By forging strategic partnerships with research institutions, cryptographic standards bodies (e.g., NIST, ENISA), and international peers, central banks can ensure that domestic responses are harmonised with global protocols, avoiding fragmentation or regulatory arbitrage.

The core argument and analysis proposed via this paper are based on the fact that the quantum resilience for central banks is not merely about upgrading systems; it is about reconstituting the institutional logic of cybersecurity governance. Central banks can embed quantum defence into the structural DNA of financial oversight through anticipatory legal reform, intersectoral collaboration and technical adaptability, thus preserving trust, integrity and systemic stability in the quantum age.

5. Public–private partnerships: The foundation for quantum resilience

The transition to quantum-safe financial infrastructure cannot be undertaken in institutional silos. Given the breadth and unpredictability of quantum threats, resilience must be constructed through robust, legally supported public-private partnerships (PPPs) that fuse technical innovation with regulatory coherence.[188] In line with the RHC's emphasis on co-regulation and agile governance, this section argues that PPPs must become the institutional cornerstone of the UK's quantum resilience strategy.[189]

At the national level, the NCSC is ideally positioned to serve as the central convening authority for PPP coordination. Drawing lessons from the United States' National Security

[182] Laima Jančiūtė, "Cybersecurity in the Financial Sector and the Quantum-Safe Cryptography Transition: In Search of a Precautionary Approach in the EU Digital Operational Resilience Act Framework" (2025) 6(2) Int Cybersecur Law Rev145, 148–9 <https://pubmed.ncbi.nlm.nih.gov/40406673/>.

[183] Bank for International Settlements, Banque de France and Deutsche Bundesbank (n 180).

[184] UK Quantum Skills Taskforce, *UK Quantum Skills Taskforce Report* (GOV.UK, 2025) <https://www.gov.uk/government/publications/uk-quantum-skills-taskforce-report/uk-quantum-skills-taskforce-report>.

[185] G7 Cyber Expert Group, "Statement on Planning for Opportunities and Risks Associated with Quantum Computing" (25 September 2024) <https://home.treasury.gov/system/files/136/G7-CYBER-EXPERT-GROUP-STATEMENT-PLANNING-OPPORTUNITIES-RISKS-QUANTUM-COMPUTING.pdf>.

[186] Eline de Jong, "Philosophy and Ethics of Risk: Better Secure than Sorry? Assessing the Quantum Cybersecurity Risk" (University of Amsterdam, 2024) <https://eprints.illc.uva.nl/id/document/12909>.

[187] Bank of England, "The Future of Finance: The Impact of Quantum Technologies on the Financial Sector" (2022) 20–22 <https://www.bankofengland.co.uk/report/2022/the-future-of-finance-quantum-technologies>.

[188] Raphael Auer, "Quantum Computing and the Financial System: Opportunities and Risks" (2024) BIS Papers No 149, 7–9 <https://www.bis.org/publ/bppdf/bispap149.pdf>.

[189] Ibid.

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Agency (NSA) quantum security programmes, the NCSC should work alongside the Bank of England, HM Treasury and critical financial institutions to establish sectoral quantum-readiness frameworks. These would include binding milestones for cryptographic migration, detailed implementation guidelines for high-risk systems (such as payments and clearing), and a legal framework for sectoral accountability.

To formalise these arrangements, the UK Government should legislate a Quantum Security Oversight Authority (QSOA), an inter-agency body with legal standing to oversee quantum transition protocols across finance, telecommunications and healthcare.[190] The QSOA would coordinate with regulators such as the FCA and Ofcom, ensuring that quantum-safe practices are sector-specific and legally enforceable. A similar approach has been proposed under the EU's Cyber Resilience Act and ENISA's Joint Cyber Unit, offering a regional model for multistakeholder cyber governance.[191]

The logic of PPPs lies not only in technical capacity-sharing but also in risk equalisation. Large systemically important financial institutions (SIFIs) often possess disproportionate quantum readiness compared to smaller firms.[192] PPP-led frameworks through shared infrastructure access, open-source cryptographic libraries and national simulation environments can help mitigate readiness asymmetry and ensure system-wide coherence.[193] This aligns with FSMA s.137G, which empowers regulators to provide proportional and coordinated risk management standards across firms.[194]

Crucially, PPPs must include structured mechanisms for feedback, transparency and dispute resolution. A centralised oversight body should publish periodic Quantum Threat Readiness Reports, informed by real-time metrics and sector consultations.[195] These reports would enable Parliament, regulators and industry to monitor quantum migration progress while providing statutory cover for anticipatory regulatory actions.[196] A Parliamentary Select Committee on Digital Resilience could be tasked with oversight, modelled after existing committees on AI and digital markets.

International engagement remains essential. The UK's financial quantum strategy must interoperate with transatlantic efforts under the 2023 US–UK Bilateral Tech Agreement and proposed G7 frameworks such as the Hiroshima Quantum Principles. Without legal alignment at the international level, quantum migration risks becoming fragmented, exposing multinational institutions to cross-jurisdictional compliance contradictions.[197]

While the PPPs are not merely instrumental for technological rollout, they are constitutionally necessary for legitimising the quantum transition.[198] By embedding quantum resilience within financial governance's legal and institutional architecture, the UK can consolidate its position as a secure, anticipatory and globally aligned financial centre in the post-quantum era.

[190] UK Government, *Regulating Quantum Technology Applications: Government Response to Recommendations Made by the Regulatory Horizons Council* (8 October 2024).

[191] Regulatory Horizons Council, *The Regulation of Quantum Technology Applications* (February 2024) 6–8, 13–14 <https://assets.publishing.service.gov.uk/media/65ddc83bcf7eb10015f57f9f/RHC_regulation_of_quantum_technology_applications.pdf>.

[192] M D Adegbola, A E Adegbola, P Amajuoyi, L B Benjamin and K B Adeusi, "Quantum Computing and Financial Risk Management: A Theoretical Review and Implications" (2024) 5(6) Comput Sci IT Res J 1210.

[193] Ibid.

[194] Financial Services and Markets Act 2000, s 137G <https://www.legislation.gov.uk/ukpga/2000/8/section/137G>.

[195] M D Adegbola and others, "Quantum Computing and Financial Risk Management: A Theoretical Review and Implications" (2024) 5(6) Comput Sci IT Res J 1210 <https://doi.org/10.51594/csitrj.v5i6.1194>.

[196] Ibid.

[197] Jess Rapson, "International Governance and Quantum Computing" (G7 Research Group, 14 June 2025) <https://g7.utoronto.ca/evaluations/2025kananaskis/rapson-quantum.html>.

[198] Ibid.

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6. Embracing the quantum opportunity in financial services

Seizing the promise of quantum computing in the financial sector requires more than risk mitigation; it demands visionary institutional design and anticipatory governance. For the United Kingdom to lead in this domain, it must not only defend against quantum threats but also actively shape the trajectory of quantum innovation within a legally robust, ethically grounded, and economically resilient framework.[199] This section synthesises earlier proposals and presents a forward-facing institutional blueprint anchored in regulatory imagination, international cooperation and capability development.

A pivotal first step lies in operationalising a QITF, an institutional vehicle to drive coherence across policy, regulation and implementation. Building upon recommendations from the Regulatory Horizons Council and the UK National Quantum Strategy, the QITF would be a bridging entity between regulators (e.g., the FCA, HM Treasury), financial institutions, industry consortia (e.g., UK Finance), and research bodies.[200] Its core remit would be to manage three strategic pillars: quantum policy integration, international regulatory harmonisation and workforce capacity-building.

The first pillar, Strategic Quantum Roadmapping, involves crafting a unified sector-wide roadmap that is not merely declarative but enforceable. This roadmap must articulate legal thresholds, migration benchmarks and risk-tiered implementation schedules.[201] In alignment with FSMA s.138I, such a framework could be embedded within the FCA's rule-making powers, offering financial firms actionable and proportionate compliance targets. These should distinguish between critical systems (e.g., payments, clearing) and auxiliary services, ensuring a phased and prioritised adoption of post-quantum cryptography.

Secondly, the QITF must advance the UK's position as a standard-setter in international regulatory coordination. Financial services operate within a globally entangled infrastructure, and divergent quantum standards could fragment risk governance, increase compliance burdens and expose the UK to transboundary vulnerabilities.[202] The QITF should facilitate engagements with the BIS, European Commission, ISO/IEC JTC 1 SC 27 and the US NIST, helping to shape interoperable norms on quantum migration, encryption resilience and incident disclosure.

The final and most structurally significant pillar is the development of a quantum-capable workforce. The UK's quantum ambition will falter without a talent pipeline that translates technical breakthroughs into financial applications. The QITF must act as a nexus for public–private–academic partnerships, working closely with institutions such as the Alan Turing Institute, Imperial College London and UKRI's Centres for Doctoral Training. This collaboration should generate specialist training programmes in cryptographic engineering, regulatory risk and quantum governance, linked to practical placements in financial institutions.[203]

Embedding quantum-specific obligations into financial regulation risks undermining the long-standing principle of technological neutrality. Hardwiring rules around a technology whose trajectory remains uncertain could introduce rigidity, discourage experimentation, or prematurely lock institutions into standards that may soon be outdated. Others contend that market incentives alone should suffice to drive migration towards post-quantum cryptography: financial institutions, motivated by reputational risk and competitive advantage, will invest in resilience faster and more flexibly than

[199] IMF, *United Kingdom: Financial Sector Assessment Program–Some Forward Looking Cross-Sectoral Issues* (IMF Working Paper, 2022) vol 2022, issue 108.

[200] National Cyber Security Centre, *Next Steps in Preparing for Post-Quantum Cryptography* (2023).

[201] UK Finance, *Seizing the Opportunities: Quantum Technology and Financial Services* (2023).

[202] ENISA (n 128).

[203] Ibid.

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regulatory mandates can dictate. A further concern is distributive: imposing statutory obligations for quantum resilience may impose disproportionate costs on smaller firms, reinforcing concentration in an already uneven financial sector. These perspectives have merit, and they remind us that anticipatory regulation always carries risks of overreach. However, these approaches, while theoretically attractive, leave significant structural vulnerabilities. Without a common legal baseline, preparedness will develop unevenly, with larger firms moving ahead while weaker actors lag, exposing the system as a whole to cascading failures. Similarly, while regulatory burdens are real, the systemic consequences of quantum-enabled disruption are of such magnitude that treating resilience as optional would be untenable. The stronger position, then, is to treat quantum readiness not as discretionary innovation but as an essential component of financial stability, one that requires law to establish binding thresholds while preserving space for adaptive implementation.

The political and regulatory capital required to sustain such a transformation is considerable. However, the costs of inaction, technological dependence, regulatory obsolescence and market destabilisation are far greater. The UK can embed quantum resilience as a strategic asset, not a regulatory afterthought, through proactive, collaborative and legally grounded institutional innovation.[204]

Ultimately, embracing the quantum opportunity must be a conscious act of national and sectoral self-determination. The UK financial sector can assert leadership in economic competitiveness, digital sovereignty and systemic trust by building the regulatory, technical and ethical infrastructure for quantum integration. Quantum safety, properly institutionalised, will be the scaffolding upon which the next era of financial innovation is responsibly constructed.

VI. Conclusion

Quantum computing is no longer a distant technological abstraction but an imminent disruptor of financial infrastructure, legal frameworks and institutional resilience. Its capacity to accelerate data processing, optimise decision-making and transform systems architecture carries profound implications for financial markets, where precision, trust and compliance are foundational. Yet, this transformative potential is matched by the scale of its risks: quantum computing imperils core cryptographic assumptions, threatens transaction integrity, and reconfigures the legal parameters of risk accountability.[205] In this context, the challenge is not merely technological but normative, legal and strategic.

This paper has argued that a quantum-safe financial ecosystem must be designed with intentionality, not improvised reactively. Financial institutions must now migrate from passive awareness to pre-emptive restructuring, embedding quantum-resistant encryption, revising governance frameworks and aligning risk protocols with emerging quantum realities.[206] Regulatory bodies, for their part, must abandon technologically neutral postures and adopt anticipatory frameworks that define enforceable standards, specify thresholds for readiness and incorporate quantum threats into systemic risk supervision and enforcement mandates.

At the centre of this transformation lies the Quantum-Safe Financial Task Force proposal, anchored in the UK's regulatory institutions but coordinated across the private sector and international bodies. Such an entity must operationalise adaptive regulation by

[204] UK Quantum Skills Taskforce, *UK Quantum Skills Taskforce Report* (24 June 2025) <https://www.gov.uk/government/publications/uk-quantum-skills-taskforce-report/uk-quantum-skills-taskforce-report>.

[205] Mauritz Kop and others, *10 Principles for Responsible Quantum Innovation* (2023) <https://law.stanford.edu/publications/10-principles-for-responsible-quantum-innovation/>.

[206] Daniel Herman and others, "Quantum Computing for Finance" (2023) 5(8) Nat Rev Phys 450.

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setting strategic migration timelines, embedding quantum-safe auditing protocols, and fostering cross-sector collaboration.[207] In parallel, central banks, including the Bank of England, must recalibrate prudential frameworks to account for quantum-induced volatility, enhance surveillance of quantum-powered high-frequency trading and safeguard monetary sovereignty through resilient cryptographic infrastructure.[208]

The United Kingdom is uniquely positioned to lead this transition. Its early-stage investments in quantum R&D, statutory agility through instruments like the FSMA, and institutional capacity in digital governance mark it as a credible global standard-setter.[209] However, leadership will only be realised through institutional coherence, legal precision and global engagement. Fragmented preparedness, either across sectors or jurisdictions, will only amplify risk.

A sustainable and secure quantum transition will also require the integration of public law values of transparency, accountability and equity into technical implementation. The migration to post-quantum standards must protect financial elites and ensure the integrity of welfare transfers, consumer banking and public sector financial services. This is not a niche regulatory upgrade but a constitutional moment in digital financial governance.[210]

The quantum transition is not a matter of if, but how. The future of financial law and risk regulation will be judged by its capacity to embrace innovation and its foresight in embedding that innovation within resilient, equitable and lawful infrastructures. Suppose the UK financial sector succeeds in doing so through strategic governance, legal reform and international cooperation. In that case, it will secure itself against quantum threats and set a global benchmark for responsible technological sovereignty in the digital era.

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[207] Regulatory Horizons Council, *Closing the Gap: Getting from Principles to Practice for Innovation-Friendly Regulation* (2022).

[208] S Doerr, L Gambacorta, T Leach, B Legros and D Whyte, "Cyber Risk in Central Banking" (2022) BIS Working Papers No 1039, September.

[209] Department for Science, Innovation and Technology, *National Quantum Strategy* (March 2023).

[210] World Economic Forum, *Quantum Security for the Financial Sector: Informing Global Regulatory Approaches* (January 2024).

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