UK FINANCE

SEIZING THE OPPORTUNITIES: QUANTUM TECHNOLOGY AND FINANCIAL SERVICES

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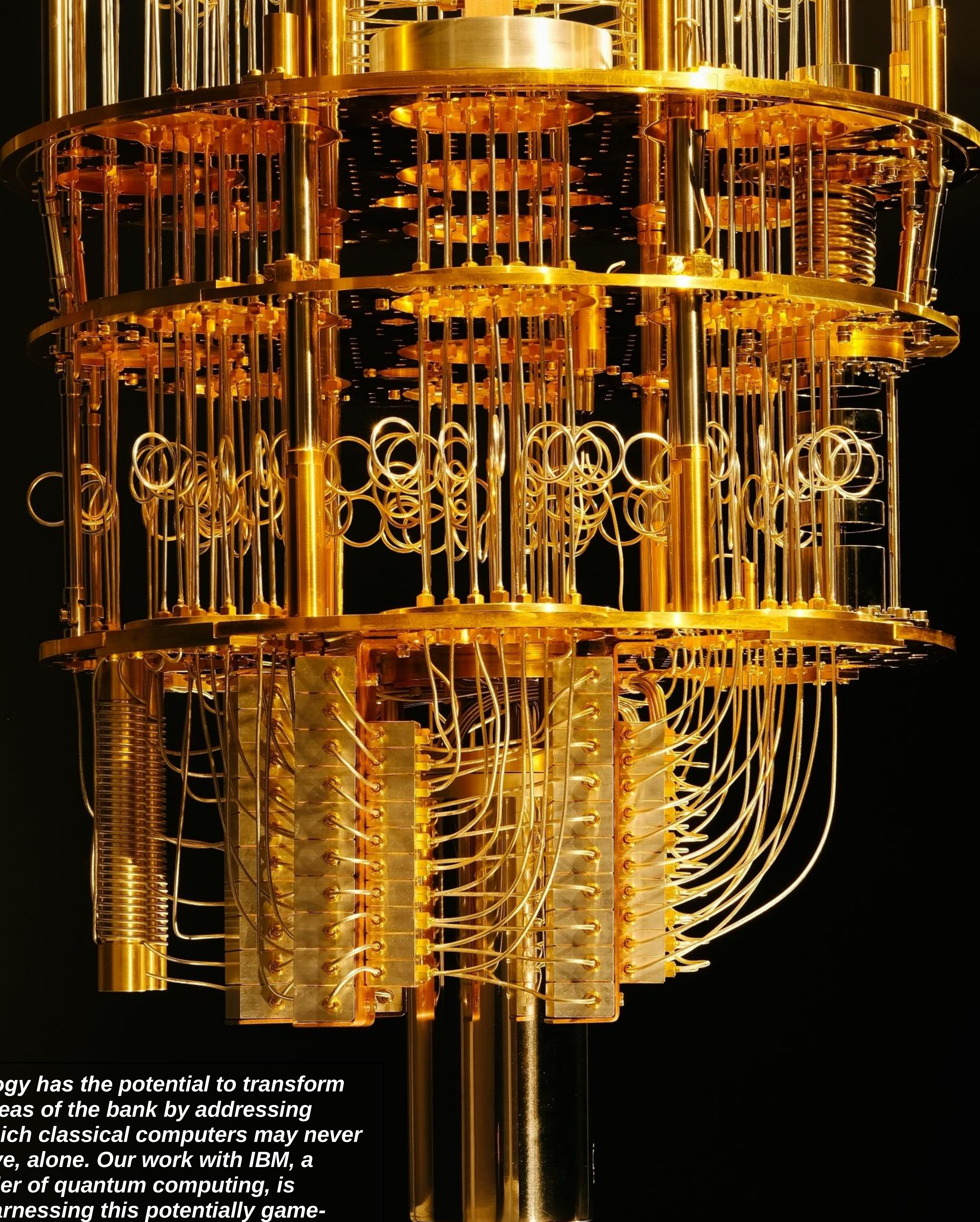
Preface

As the financial services sector considers new innovations and emerging technologies, it is evident that advances in quantum computing hold significant implications for firms, their customers, and the wider market. Industry must comprehensively grasp the opportunities presented by quantum computing, but also address the associated risks.

In a collaborative effort, UK Finance and IBM offer insight into the evolution of quantum technology, its ramifications for industry, and practical steps that can be taken if these opportunities are to be grasped. This paper should be read in conjunction with UK Finance's *Minimising the Risks: Quantum Technology and Financial Services* paper to gain a complete picture

Contents



"This technology has the potential to transform how we run areas of the bank by addressing challenges which classical computers may never be able to solve, alone. Our work with IBM, a leading provider of quantum computing, is essential to harnessing this potentially game-changing technology for financial services."

Colin Bell, Chief Executive Officer, HSBC Bank plc and HSBC Europe

Executive Summary

Quantum computing presents a unique opportunity for the UK's financial services sector as it seeks to harness new innovations and assess emerging technologies. Widely seen as a potential game-changer, this paper outlines how quantum computing could bring transformative efficiencies to important aspects of firm operations if it were to be applied to a several critical functions common to most firms.

The key opportunities presented by quantum technology ncludes:

1. **Risk Analysis:** Quantum computing promises to enhance risk analysis capabilities by processing vast amounts of data and running complex simulations at unprecedented speeds, leading to better-informed investment and business decisions.
2. **Compliance**: Quantum computing's potential to streamlining compliance processes by quickly identifying patterns and discrepancies in datasets may lead to reductions in the time and resources required to ensure regulatory adherence.
3. **Investments**: Quantum computing could dramatically improve portfolio optimisation and asset management by processing complex calculations rapidly, identifying optimal investment strategies, and maximising returns while minimising risks.
4. **Data Privacy**: Securing sensitive data through quantum cryptography and encryption techniques will ensure the protection of customer and transactional information.
5. **Data Management**: Revolutionising data management in financial services by processing data quickly and efficiently using quantum computing will enable better decision-making, trend identification, and overall operational efficiency.
6. **Operations**: Quantum computing will optimise operational processes, such as logistics, supply chain management, and resource allocation by finding the most efficient solutions to complex problems.
7. **Sales**: Enhancing sales strategies through advanced data analytics and customer segmentation, quantum computing could identify new market opportunities and personalised product offerings.
8. **Pricing**: Improving pricing models by quickly analysing complex market data and identifying optimal pricing strategies using quantum computers will result in more accurate and competitive pricing.

Quantum computing's potential to enhance existing processes, create new capabilities, and drive innovation is unparalleled. As financial institutions continue to face challenges posed by a rapidly changing financial landscape, embracing quantum computing technologies can unlock new opportunities for growth and ensure their competitiveness in the global market.

Recommendations

To realise these opportunities, UK Finance recommends that the financial services sector:

- Establish a quantum computing task force, charged with Develop a long-term quantum computing strategy.
- Invest in quantum computing education and training.
- Collaborate with quantum computing research institutions and industry partners.
- Develop proof-of-concept projects.

Section 1: An introduction to quantum technology

Quantum computing is a technology that harnesses the powerful principles of quantum mechanics to revolutionise current computation methods. Whilst classical computers process information using bits represented as 0s and 1s, quantum computers utilise quantum bits (qubits) that can encode information in a fundamentally different manner. This unique approach enables quantum computers to tackle complex problems in entirely new ways.

What is Superposition?

A qubit can perform an important trick: placing the quantum information it holds into a state of superposition, which represents a combination of all possible configurations of the qubit. Groups of qubits in superposition can create complex, multidimensional computational spaces. Complex problems can be represented in new ways in these spaces.

The strength of quantum computing lies in three fundamental principles of quantum mechanics: superposition, interference, and entanglement. These three principles, among others, empower quantum computers to potentially perform complex computations in an exponentially large computation space that would be intractable for classical computers or require exponentially more classical resources to compute. Put simply quantum computers will likely solve a number of problems faster, cheaper and more efficiently.

For instance, problems such as credit risk analysis which are currently computationally expensive from a time and resource perspective can potentially be sped up significantly which would allow more accurate calculation and therefore more accurate capital reserve determinations.

Quantum computing has many valuable application areas in many industries. This includes simulating nature, mathematics and processing data with complex structure (machine learning) and optimisation and simulation. Within these use case areas, the ability to solve a problem more efficiently, more accurately or faster with a quantum computer than using purely classical computation alone is defined as the point of “Quantum Advantage”. This includes both solving problems we note as

What is Entanglement?

Quantum entanglement is an effect that correlates the behaviour of two separate things. When two qubits are entangled, changes to one qubit directly impact the other.

What is Interference?

In an environment of entangled qubits placed into a state of superposition, there are waves of probabilities. These waves can build on each other when many of them peak at a particular outcome or cancel each other out when peaks and troughs interact. These are both forms of interference.

A computation on a quantum computer works by preparing a superposition of all possible computational states. A quantum circuit, prepared by the user, uses interference selectively on the components of the superposition according to an algorithm. Many possible outcomes are cancelled out through interference, while others are amplified. The amplified outcomes are the solutions to the computation.

intractable today, and solving problems we may already be able to solve today, but more efficiently (i.e., derivative pricing.)[1]

Quantum computing's advance

Quantum computing's remarkable journey of advancement promises to usher in a new era of computation that could challenges the boundaries of classical computing paradigms. Over the past few decades, this field has witnessed significant progress, marked by a series of ground-breaking milestones. From initial theoretical concepts to experimental realisations of quantum bits (qubits) and their manipulation, the journey has been both transformative. As we stand at the intersection of theoretical promise and tangible progress, it is important understand the key milestones achieved thus far, appreciate their significance, and consider the potential trajectories that quantum computing might take in the foreseeable future.

Understanding these milestones matters. They serve as crucial guideposts for businesses operating within the financial services sector, and while the future implications of quantum computers remain uncertain, it is clear that the pace of technological advancement is accelerating. Enterprises seeking to remain at the cutting edge of innovation must grasp the intricacies of this evolving landscape and proactively monitor indicators of progress (and potential disruptions) to effectively navigate this transformative journey.

After decades of R&D and billions of dollars of investment, today quantum computers are no longer purely theoretical. Large technology firms such as IBM, Google, Amazon and Microsoft are all developing quantum hardware and we are now beginning to see the impact of this progress with a rapidly developing quantum computing market. By some estimates, the global Quantum Computing as a Service (QCaaS) market could reach $26 billion by 2030.[2]

While much remains uncertain, there is an emerging consensus that the next few years will be the tipping point for the technology. In a recent UK cross industry survey nearly half of executives surveyed (48%) believe quantum computing will play a significant role in their industries by 2025.[3]

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<tr><th>Company</th><th>Qubit Tech</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th></tr>
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1 https://arxiv.org/pdf/1905.02666.pdf

2 https://media.defense.gov/2021/Aug/04/2002821837/-1/-1/1/Quantum_FAQs_20210804.PDF

3 https://assets.ey.com/content/dam/ey-sites/ey-com/en_uk/topics/emerging-technology/quantum/ey-quantum-readiness-survey-2022.pdf

Company	Qubit Tech	2023	2024	2025	2026	2027	2028	2029	2030
Rigetti	Superconducting	84		336		1,000+		4,000+	

TABLE 1*:* The projected future improvements (in terms of power) that some of the world's leading quantum computers will achieve between 2023-2030*. (Source: CITI Quantum report 2023 – page 23 - Citi GPS: Global Perspectives & Solutions - QUANTUM COMPUTING Moving Quickly from Theory to Reality)*

Various technology companies are developing quantum computers and releasing roadmaps to meet this expectation. Table 1 details the number of qubits that projected quantum machines being developed by many of the leading players will have across the next 7 years, but while qubit count (i.e., the scale of quantum computers) is generally used as the main indicator of quantum machine development, scale isn't the only driver of progress. The speed in which quantum computers operate and quality of the computation are also significant factors, alongside various innovations that have enabled continued allow improvement in these areas. Many of these have been facilitated by both the physical engineering of the quantum computers and logical components such as intelligent orchestration of computational jobs or error mitigation techniques.

A 2023 *Nature* paper investigated and compared classical methods of a specific calculation with quantum methods using a currently available 127-qubit quantum machine. This article evidenced the achievement of a result out of reach for classical simulations alone and argued that the result indicated promise for utility of a quantum computer at current levels of fault tolerance. This 'benchmark' experiment suggests quantum computers could have useful real-world applications within two years.[4] Experts such as John Martinis, a physicist at the University of California, Santa Barbara commenting that "it makes you optimistic that this will work in other systems and more complicated algorithms".[5]

[4] https://www.nature.com/articles/d41586-023-01965-3
[5] https://www.nature.com/articles/d41586-023-01965-3

Section 2: Understanding quantum's potential

Seizing the opportunities presented by the potential of quantum computing does not require a detailed understanding of how a quantum computer works; rather, it requires an understanding of *how* this technology might be applied to existing business processes to drive efficiencies and maximise value. Firms wishing to take advantage of the promise of quantum computing need to understand how quantum computers could be applied to existing processes and consider which business processes are best placed to take advantage of this innovation.

Regardless of which specific processes quantum computers are applied to, quantum technology has the potential to revolutionise various aspects of the financial services sector. It will do this by solving problems that were, for classical computers, previously intractable or time-consuming, via three ways:

The application of machine learning and supporting artificial intelligence

The first means by which quantum computing promises to revolutionise financial services is via the application of machine learning and artificial intelligence (AI). These technologies – developments of which have already starting to be felt across financial sector – enable advanced data analysis, predictive modelling, and intelligent decision-making. Quantum computing could be used to create machine learning models which could detect different patterns that current classical methods cannot obtain, whilst needing less data to train and less time to derive insights. This could lead to more accurate and timely predictions, helping financial institutions to better assess risks, detect fraud and support AML efforts. Furthermore, quantum-enhanced AI can enhance customer experience by providing personalised financial advice and service offerings, tailored to individual needs and preferences.

Optimisation

The second key business process where quantum computing promises to bring significant innovation is optimisation. Financial institutions constantly face large complex optimisation problems, such as portfolio management, asset allocation, and trading strategies. Solving these problems efficiently is critical to maximising returns and minimising risks. Classical computers often struggle with these tasks due to their computational complexity and the need to explore a vast solution space. Quantum computing, with its ability to perform calculations faster than classical computers, could potentially find more optimal solutions to these problems more efficiently and accurately. This could lead to financial institutions optimising their portfolios better, managing risks more effectively, and ultimately improving their overall financial performance.

Simulation

Finally, financial services firms rely heavily on simulations to model and predict the behaviour of markets, as well as to assess the impact of various strategies and scenarios. Quantum computing promises to revolutionise this process by enabling more accurate and faster simulations, ultimately leading to more informed decision-making and better management of risks.

With quantum computers able to simulate complex financial systems and model market dynamics more efficiently than classical computers, it will provide financial institutions with deeper insights into market trends and potential risks. The benefits will not just be for firms; for regulators and supervisors, enhanced simulation capability can also be applied to stress testing, allowing regulators to assess the resilience of financial institutions under various adverse scenarios more effectively. Leveraging quantum computing for simulations will allow all stakeholders to make more informed decisions, better manage risks, and ensure more accurate compliance with regulatory requirements.

Harnessing the power of quantum computing will help financial institutions unlock new levels of efficiency, accuracy, and speed in their operations. This will inevitably lead to better decision-making, risk management, and overall financial performance. As the UK continues to invest in and develop quantum computing technologies, real change will start to occur once industry applies these innovations to tasks unique to financial services.

Quantum computing and the implications for financial services

Recent advances in quantum technology presents the UK financial services sector in particular with a unique opportunity to innovate core aspects of its operations. This potential is not limited to operational improvements however; quantum computing promises to completely revolutionise the way financial services firms do business at a task and product level as well.

This section outlines key businesses areas or processes within financial services that could specifically benefit from the application of quantum technology in the manner described above. Each business area (or use case) demonstrates how quantum computing can create value across various functions, highlighting the transformative impact this technology could have on tasks specific to financial services. In exploring these use cases, firms can gain insights into the areas where quantum computing can make the most significant impact and develop strategies to capitalise on these opportunities.

Opportunity 1 - Risk analysis

The ability of quantum computing to handle large-scale, complex calculations such as conditional Value-at-Risk or economic capital requirements at unprecedented speeds potentially makes it a game-changer for financial sector risk analysis. Traditional risk analysis methods, constrained by classical computing limitations, often involve simplifications and assumptions that can lead to inaccuracies. Quantum computing has the potential to better represent the complexity of real-world financial systems by speeding up the calculation of these risk measures, enabling financial institutions to model a wider range of scenarios and calculate probabilities more accurately and efficiently. This enhanced risk analysis capability allows for better-informed investment and business decisions, ultimately leading to improved financial stability and resilience.

Barclays, a leading UK-based financial institution, is collaborating with IBM to explore the use of quantum computing in risk analysis and optimisation. Their partnership focuses on areas such as credit risk analysis and collateral management, where quantum computing can enable more accurate modelling and efficient allocation of resources. This collaboration demonstrates the potential of quantum computing to transform critical aspects of the financial services sector, setting a precedent for other institutions to follow.

Opportunity 2 - Compliance

Quantum computing can revolutionise compliance processes within the financial services sector by streamlining and identifying patterns and discrepancies with remarkable speed. Regulatory compliance is an increasingly complex and resource-intensive task for financial institutions, as they face evolving regulations and the need to process vast amounts of data. Quantum computing can greatly reduce the time and resources required to ensure regulatory adherence, improving efficiency while maintaining a high level of accuracy and effectiveness.

By leveraging quantum computing in compliance processes, financial institutions can more effectively detect and prevent potential issues such as fraud, money laundering, and other financial crimes. This enhanced capability can result in substantial cost savings, as well as improved reputation and trust among customers, supervisors, and regulators. Additionally, quantum computing can enable more proactive compliance management, allowing financial institutions to anticipate and adapt to regulatory changes more efficiently. HSBC, for example, has been working with technology partners to investigate using quantum computing to enhance fraud detection techniques.[6] [7]

With the cost of compliance for financial institutions estimated to be over $270 billion per year, the potential savings that even small efficiency improvements brought about by quantum computing would be substantial.

Opportunity 3 – Investments

Quantum computing has the potential to dramatically transform investment management and portfolio optimisation. By processing complex calculations rapidly, financial institutions can identify optimal investment strategies, more accurately analyse potential returns, and minimise risks associated with their investment portfolios. This enhanced capability can lead to improved decision-making in asset allocation, ultimately resulting in better investment performance.

In addition to portfolio optimisation, quantum computing can also be applied to other aspects of investment management, such as trading algorithms and market predictions. By analysing vast amounts of financial market data in real-time, quantum computing can enable financial institutions to identify emerging trends and market inefficiencies more quickly, allowing them to capitalise on new opportunities before their competitors.

[6] https://www.hsbc.com/who-we-are/businesses-and-customers/hsbc-and-quantum

Quantum computing can also improve the modelling of financial instruments, such as options and derivatives, by considering a wider range of factors and scenarios, leading to more accurate pricing and risk assessment. This enhanced understanding of financial instruments can further contribute to better investment decision-making.

NatWest, a major UK-based financial institution, has partnered with Fujitsu to explore the use of quantum computing for portfolio optimisation. Through this collaboration, NatWest aims to improve its investment strategies and risk management by leveraging the power of quantum computing to analyse complex investment scenarios and identify optimal asset allocations. This partnership exemplifies the transformative potential of quantum computing in the field of investment management.

Opportunity 4 – Data management

The ability of quantum computing to process data more efficiently has the potential to revolutionise financial data management. In enabling financial institutions to analyse and process datasets more efficiently, quantum computing can lead to better decision-making, trend identification, and overall operational efficiency.

Quantum computing can enhance data management in areas such as fraud detection, customer segmentation, and credit scoring. By rapidly processing and analysing customer transaction data, quantum computing can help financial institutions identify suspicious activities, better understand customer preferences, and more accurately assess creditworthiness.

In addition to improving data management processes within financial institutions, quantum computing can also enable the development of new financial products and services that rely on advanced data analytics, such as personalised financial advice and tailored investment solutions.

JPMorgan Chase, a leading global financial institution, is working with IBM to explore how quantum computing can be applied to various data management challenges, including trading strategies, portfolio optimisation, and risk analysis. Through this collaboration, JPMorgan Chase aims to harness the power of quantum computing to enhance its data-driven decision-making processes and gain a competitive advantage in the financial services sector.[8]

Opportunity 5 – Operations

Quantum computing has the potential to significantly optimise operational processes within the financial services sector, such as logistics, supply-chain management, and resource allocation. By finding the most efficient solutions to complex problems that are currently beyond the capabilities of

[8] https://www.ibm.com/case-studies/jpmorgan-chase-quantum-computing

classical computers, financial institutions can reduce costs, improve overall performance, and better serve their customers.

For example, quantum computing can help financial institutions optimise their cash and liquidity management by identifying the most efficient allocation of funds across different accounts, branches, and currencies. This can ensure optimal use of resources and minimise transaction costs, leading to increased profitability.

In addition, quantum computing can be applied to optimise various operational processes within financial institutions, such as loan processing, customer service, and fraud detection. By identifying patterns and anomalies, quantum computing can enable financial institutions to streamline their operations, reduce response times, and improve the overall customer experience.

Financial institutions could also look at the use quantum computing to optimise their workforce management by analysing employee skills, performance, and availability to determine the most effective allocation of resources. This can lead to improved productivity, employee satisfaction, and reduced operational costs.

Goldman Sachs, a leading global investment bank, has invested in quantum computing start-up QC Ware to explore applications in finance, including optimisation problems related to trading and risk management. By leveraging quantum computing, Goldman Sachs aims to optimise various operational processes, reduce costs, and improve overall performance in the competitive financial services sector.

Opportunity 6 – Sales

Quantum computing has the potential to revolutionise sales strategies by providing advanced data analytics and customer segmentation capabilities. By rapidly processing and analysing large customer datasets, quantum computing can help financial institutions identify new market opportunities, personalise product offerings, and enhance overall customer satisfaction.

One way quantum computing can improve sales strategies is by enabling more accurate customer segmentation and targeting. By analysing customer behaviour, preferences, and demographics, quantum computing can help financial institutions identify high-value customer segments and tailor their sales and marketing efforts accordingly. This can result in more relevant and effective sales campaigns and increased revenue.

Quantum computing has the potential to process large customer datasets up to 100 million times faster than classical computers, enabling rapid identification of sales opportunities and more effective targeting of high-value customer segments.[9]

[9] https://www2.deloitte.com/xe/en/insights/industry/financial-services/financial-services-industry-predictions/2023/quantum-computing-in-finance.html

Additionally, quantum computing can help financial institutions develop more sophisticated pricing models for their products and services. By analysing complex market data and customer preferences, quantum computing can identify optimal pricing strategies that maximise both profitability and customer satisfaction.

Improved sales forecasting and inventory management could also be possible with use of quantum computers, allowing financial institutions to better align their resources with market demand. By accurately predicting sales trends and customer needs, financial institutions can also optimise their product offerings and reduce the risk of stockouts or overstocked inventory.

Opportunity 7 – Pricing

Quantum computing offers the potential to revolutionise pricing models by rapidly analysing complex market data and identifying optimal pricing strategies. Accurate and competitive pricing is essential for the success of financial products and services, and quantum computing can enable financial institutions to optimise their pricing models, resulting in increased profitability and customer satisfaction.

For instance, quantum computing can facilitate the development of sophisticated pricing models for intricate financial instruments like options, derivatives, and structured products. By accounting for a broader range of factors and scenarios, quantum computing can produce more accurate pricing and risk assessments, leading to better investment decision-making and risk management.

In retail banking, quantum computing can optimise pricing strategies for loans, deposit rates, credit card fees, and insurance premiums. By examining customer behaviour, market conditions, and the competitive landscape, quantum computing can help financial institutions determine the optimal pricing structure that balances profitability and customer satisfaction. Moreover, quantum computing can enhance pricing models for foreign exchange and fixed income trading by swiftly analysing extensive market data and pinpointing arbitrage opportunities and optimal trading strategies. This enables financial institutions to capitalise on market inefficiencies and improve overall trading performance.

BBVA, a multinational financial institution, is exploring the application of quantum computing in optimising currency arbitrage and pricing financial instruments. Through this work BBVA aims to harness the power of quantum computing to refine its pricing models and gain a competitive edge in the financial services sector.[1]

Opportunity 8 – Human resources

Quantum computing has the potential to significantly transform human resources processes such as recruitment, talent management, and workforce optimisation. In a highly competitive landscape, financial institutions engaged in a competition for the best talent striving to attract and retain the best professionals in the sector need an edge. Using quantum computers to streamline HR processes may provide it.

For example, quantum computing can be used to quickly model datasets related to job applicants, such as their skills, qualifications, and employment history, enabling financial institutions to identify the most suitable candidates and reduce the time and resources spent on recruitment. This can lead to more efficient hiring practices and a stronger talent pool.

In addition, quantum computing can optimise workforce management by analysing employee performance, skills, and availability to determine the most effective allocation of resources. This can result in improved productivity, employee satisfaction, and reduced operational costs. Furthermore, quantum computing can help financial institutions identify skill gaps and training needs, allowing them to develop targeted professional development programs and improve overall workforce capabilities.

Opportunity 9 – Environmental efficiency

High performance computing uses significant amounts of energy to perform large and complex calculations. Since quantum computation is fundamentally more energy efficient than large-scale high-performance computing, there is an opportunity to redistribute problems that are currently solved in this way to reduce the environmental footprint of financial services institutions.

It is expected that quantum computers will not require cooling in the same way as modern high-performance computers. Ongoing and expected advances in quantum computing are expected to see the power consumption reduced over time. The quantum computing industry is racing forward to make the control electronics (which currently consume the majority of the power per qubit), more efficient. Innovation is happening across many platforms to develop cryogenic control electronics which will vastly reduce the power consumption. As quantum computing technology scales and industrialises there is a clear opportunity for the platform to become high a highly efficient computing option.

Spotlight

The following sections showcases the transformative impact of quantum computing on various functions within financial institutions.

Fraud detection, trade surveillance and anti-money laundering

Quantum computing can significantly enhance fraud detection capabilities within the financial services sector by rapidly analysing datasets and identifying patterns that may indicate fraudulent activity. By processing vast amounts of transaction data, quantum computing can help financial institutions to detect and prevent fraud and money laundering more effectively, protecting both the institutions and their customers whilst maintaining market integrity, comply with regulatory requirements, and safeguarding their reputation.

Spotlight on fraud detection trade surveillance and anti-money laundering

One of the critical challenges faced by current fraud detection systems is the high rate of false positives. According to a report by Aite-Novarica, more than $11 billion of U.S. online sales in 2021 were lost due to false declines1. These inaccuracies can lead to unnecessary investigations, increased operational costs, and negatively impact customer experience by causing delays and disruptions in their transactions. With the growing threat of cyberattacks and data breaches, safeguarding sensitive financial information has become more critical than ever. The global average cost of a data breach in 2023 was USD 4.45 million, a 15% increase over 3 years.[10]

An illustration of the need for improvement and advancement in this area is the stress event of the COVID-19 pandemic which caused elevated market volatility and change in customer behaviour. During this period from March 2020 to March 2021, the volume of fraud incidents increased by almost a quarter (24%) it is also estimated that 4.3% of GDP in the UK is laundered per year.[11] [12]

By leveraging quantum computers, fraud detection techniques can be enhanced, ensuring the protection of sensitive data and the integrity of financial transactions. Quantum computing could address this issue by enabling more sophisticated and accurate fraud detection machine learning models that can identify patterns and anomalies that would be difficult or impossible for classical computers to detect, whilst also requiring less training data and providing faster insight.1 This enhanced fraud detection capability can help financial institutions reduce false positives, improve operational efficiency, and provide a seamless customer experience. Quantum machine learning can also be beneficial to Anti Money Laundering (AML) approaches due to the same need for advanced pattern matching and the recognition of abnormal behaviour is complex flows of data.

Trade surveillance can also benefit significantly from quantum computing. Financial institutions are required to monitor and analyse trading activities to identify instances of market manipulation, insider trading, and other illicit practices.

[10] https://www.experian.com/innovation/thought-leadership/report-the-ecommerce-fraud-enigma-quest.jsp
[11] https://credas.com/news/oecd-money-laundering-leader-board/
[12] https://victimscommissioner.org.uk/news/who-suffers-fraud/

The complex nature of financial markets and the sheer volume of data involved can make this a daunting task for classical computers. IDC's Global DataSphere, which forecasts the amount of data that will be created on an annual basis, predicts that over the next five years, data will grow at a compound annual growth rate (CAGR) of 21.2% to reach more than 221,000 exabytes (an exabyte is 1,000 petabytes) by 2026.[1]

Quantum computers could significantly improve the effectiveness and speed of trade surveillance systems by identifying patterns and anomalies that would be difficult or impossible to detect whilst again requiring less training data. This will not only help financial institutions ensure compliance with regulatory requirements but also contribute to the overall stability and integrity of the financial markets.[13]

In summary, quantum computing can significantly enhance fraud detection and trade surveillance. By harnessing the power of this cutting-edge technology, financial institutions can protect their customers and their businesses from the growing threats of fraud and cyberattacks, while also improving operational efficiency and customer experience. As we further explore the opportunities that quantum computing presents for the financial services sector, it is crucial to consider the potential impact and benefits of these advanced technologies in ensuring a safe and secure financial ecosystem.

Risk assessment and pricing

Quantum computing has the potential to significantly improve risk assessment and pricing models within the financial services sector by rapidly processing complex market data and identifying optimal pricing strategies. Accurate and competitive pricing is a critical factor in determining the success of financial products and services, and quantum computing can enable financial institutions to optimise their pricing models and better assess potential risks, resulting in increased profitability and more informed decision-making.

Spotlight on risk assessment and pricing

Monte Carlo simulations are widely used in finance for assessing the risk and uncertainty associated with complex financial models, such as options pricing, portfolio optimisation, and market risk analysis.

These simulations involve generating many random scenarios to evaluate the potential outcomes of various financial decisions. However, due to the complexity involved, Monte Carlo simulations can be computationally intensive and time-consuming when performed on classical computers therefore vast simplification and assumptions are made. Most of the models to estimate different risk exposures are battling trade-offs between complexity, reality, and number of risk factors with boundaries derived from stringent regulatory requirements.

Quantum computing can significantly accelerate Monte Carlo simulations therefore allowing more agile risk calculations considering and simulating a larger number of variables.

[13] https://arxiv.org/pdf/2012.03819.pdf

A study by IBM Research demonstrated that there is a quantum algorithm that holds the potential to speed up Monte Carlo simulations quadratically compared to classical algorithms. This acceleration can enable financial institutions to perform more in-depth and accurate risk assessments in real-time, leading to better decision-making and improved financial performance.

To illustrate the value of this, when calculating economic capital requirements based on credit risk, financial institutions must make assumptions that cause the amount of capital required to greater than genuinely required and more accurate models offer the potential to enable banks to streamline the allocations of capital to generate increased returns. The potential to be more accurate and efficient when calculating risk doesn't just align to economic capital requirements but wherever Monte Carlo like simulation is performed such as derivative pricing or market simulation.

Accurate pricing is crucial for various financial instruments, such as derivatives, bonds, and insurance products, as it directly affects the profitability and risk management of financial institutions. Quantum computing can enable more sophisticated pricing models that can consider a wider range of factors and market conditions, leading to more accurate and efficient pricing strategies. Option pricing and valuation can be significantly enhanced by quantum computing, enabling more accurate valuations of derivatives and complex financial instruments. Traditional option pricing models, such as the Black-Scholes model, can be computationally intensive and struggle to accurately price complex options with multiple variables and constraints. In contrast, quantum computing can efficiently solve these complex pricing problems. For example, a study by Barclays showed that quantum algorithms could reduce the time required to calculate the price of complex financial options from hours to minutes.[15]

This speed-up can improve pricing mechanisms by enabling faster and more accurate arbitrage detection. Arbitrage opportunities arise when there are discrepancies between the prices of financial instruments in different markets. Identifying and capitalising on these opportunities by detecting these value discrepancies more accurately could be highly profitable for financial institutions. Quantum computing can accelerate the process of identifying arbitrage opportunities by analysing vast amounts of market data and pricing information in real-time, allowing financial institutions to respond more quickly and efficiently.[16]

In the financial services sector quantum computing has the potential to transform risk assessment and pricing by enabling more accurate and efficient models that can handle complex data and incorporate a wide range of factors. By harnessing the power of quantum computing, financial institutions can improve their decision-making, risk management, and overall financial performance. As we continue to explore the opportunities presented by quantum computing, it is essential to consider its potential impact and benefits in critical areas such as risk assessment and pricing, which are fundamental to the success and stability of the UK financial services sector.

Optimisation, portfolio management, and improving investment strategies

Quantum computing can dramatically transform investment management and portfolio optimisation within the financial services sector. By processing complex calculations rapidly, financial institutions

[14] https://arxiv.org/pdf/2208.07963.pdf
[15] https://www.computerweekly.com/news/252472462/Barclays-demonstrates-proof-of-concept-quantum-clearing-algorithm
[16] https://research.ibm.com/publications/efficient-state-preparation-for-quantum-amplitude-estimation

can identify optimal investment strategies, more accurately analyse potential returns, and minimise risks associated with their investment portfolios. This enhanced capability can lead to improved decision-making in asset allocation and more effective investment strategies.

Spotlight on optimisation, portfolio management, and improving investment strategies

Quantum computing has the potential to significantly enhance optimization, portfolio management, and investment strategies in the financial services industry by efficiently solving complex mathematical models and leveraging quantum machine learning algorithms. This section will explore the impact of quantum computing on these critical aspects of finance, providing examples and data points to illustrate the potential benefits of this cutting-edge technology on portfolio optimization, management, and investment strategies.

Portfolio optimisation is a crucial process in finance, as it involves selecting the best combination of assets to maximize returns while minimising risks. This process requires considering a vast number of variables and constraints, such as asset correlations, market conditions, risk factors, and investment goals. Classical computers often struggle with portfolio optimisation due to its computational complexity, particularly when dealing with multiple constraints.

Quantum computing can significantly improve portfolio optimisation by leveraging its ability to process and analyse vast amounts of data at an exponential speed. Quantum algorithms can efficiently solve complex optimisation problems that are currently intractable for classical computers. For example, a study by BBVA and Spanish start-up Multiverse demonstrated that a quantum algorithm could find an optimal portfolio solution up to 10,000 times faster than classical algorithms for certain instances of the problem. This speedup can enable financial institutions to optimise their investment portfolios in real-time, leading to better risk management and higher returns. [17]

In addition to portfolio optimisation, quantum computing can also enhance investment strategies by leveraging quantum and machine learning algorithms to identify patterns and make predictions from large and diverse financial datasets.

In addition to portfolio optimisation, quantum computing can also enhance other aspects of portfolio management, such as rebalancing and risk analysis. Quantum computers can process complex mathematical models more efficiently than classical computers, allowing financial institutions to monitor and adjust their portfolios more effectively.

This can help institutions maintain their target asset allocations, minimise transaction costs, and better manage risks associated with market fluctuations and other factors.

High-frequency trading relies on the ability to execute trades within fractions of a second, capitalising on small price discrepancies in the market. According to a report by J.P. Morgan, quantum computing could potentially process trading data up to 100 times faster than classical computers. This increased speed can lead to more efficient markets and better investment outcomes.[18]

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[17] https://www.bbva.com/en/bbva-and-multiverse-showcase-how-quantum-computing-could-help-optimize-investment-portfolio-management/
[18] https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3470756

Quantum computing has the potential to revolutionise optimisation, portfolio management, and investment strategies in the financial services industry. By harnessing the power of this cutting-edge technology, financial institutions can optimise their investment portfolios, reduce risk, and maximise returns by efficiently solving complex mathematical models, considering a vast number of variables and constraints, and leveraging quantum and machine learning algorithms.

The importance of collaboration

As the financial services sector seeks to exploit the potential of quantum computing, collaboration between industry players, national governments, and international organisations will play a crucial role in driving innovation and fostering the widespread adoption of this technology.

Public-private partnerships can facilitate the development of quantum computing infrastructure, research, and talent, enabling the financial services sector to harness the power of quantum computing more effectively. One such example is the UK's National Quantum Technologies Programme, which aims to accelerate the development and commercialisation of quantum technologies through collaboration between academia, industry, and government.[19]

Financial institutions can also benefit from participating in industry consortia and working groups focused on quantum computing. These initiatives enable knowledge sharing, collaboration on research projects, as well as the development of sector wide standards and best practices. A notable example is the Quantum Economic Development Consortium (QED-C) that bringing together industry leaders, academic institutions, and government agencies to advance the development and commercialisation of quantum technologies.[20]

Financial sector leaders such as JPMorgan Chase and Barclays are already investing in quantum computing research and collaborating with technology providers like IBM and Fujitsu, exploring applications in finance. By partnering with technology leaders, financial institutions can access cutting-edge expertise and resources, enabling them to stay at the forefront of quantum computing innovation.

Academic institutions also play a vital role in driving innovation in quantum computing. By collaborating with universities and research institutions, financial services firms can access a wealth of knowledge and expertise, as well as contribute to the development of new quantum computing technologies and applications. For example, University College London (UCL) recently launched a quantum computing business to develop quantum computing hardware and software solutions for various industries, including finance.[21]

Another approach to exploiting quantum computing opportunities is through venture capital investments in quantum computing start-ups. By investing in promising early-stage companies, financial institutions can gain exposure to new technologies and potentially benefit from their growth and success. For example, Goldman Sachs has invested in quantum computing start-up QC Ware,

[19] https://uknqt.ukri.org/
[20] https://quantumconsortium.org/
[21] https://www.ucl.ac.uk/news/2023/feb/ucl-spinout-raises-ps42-million-develop-quantum-processors

exploring applications in finance, including optimisation problems related to trading and risk management.[22]

In recent years, there has been a surge in commercial and private equity investment in quantum computing, as both established companies and start-ups recognise the potential transformative impact of this technology across various industries, including the financial services sector. This increasing investment trend highlights the growing confidence in the capabilities of quantum computing and its potential to revolutionise the way businesses operate and compete in a rapidly evolving digital landscape.

Several major technology companies, such as IBM, Google, Intel and Microsoft, have made significant investments in quantum computing research and development, aiming to create powerful quantum computers and drive innovation in the field. These industry giants are not only investing in the technology itself but also partnering with smaller companies and research institutions to explore novel applications of quantum computing and accelerate its adoption across various industries. IDC, a leading global research firm, recently published a quantum computing assessment of the market which sets out the forecast that the Quantum Computing market is expected to grow to $7.6bn by 2027 with a range of technology providers driving this growth including IBM, Rigetti Computing, Quantinuum, IonQ, IQM, PASQAl and Xanadu[23.]

In total, over $34bn of government investments have been announced in relation to quantum computing as nations contribute to the development and adoption of quantum computing by providing funding, resources, and support for research and development initiatives.[24] In the UK, the Government has committed over £2.5 billion to the *National Quantum Technologies Programme* which aims to accelerate the development of quantum technologies and establish the UK as a global leader in this field.[25]

On the international level, cooperation between countries can foster the exchange of knowledge, resources, and best practices in quantum computing. For instance, the European Quantum Technologies Flagship is a €1 billion, 10-year initiative that brings together research institutions, industry partners, and governments across Europe to advance quantum technologies and drive innovation in areas such as computing, communication, and sensing.[26]

International organisations such as the World Economic Forum (WEF) and the International Telecommunication Union (ITU) are also playing a role in promoting quantum computing development and adoption by providing a platform for collaboration and dialogue between stakeholders from different sectors and regions. The ITU is driving cross industry global collaboration, including the development of a financial sector wide quantum computing roadmap.

Financial services firms can also collaborate with other industries to explore cross-sector applications of quantum computing. For example, the quantum computing in the NISQ Era and Beyond initiative brings together experts from finance, healthcare, transportation, and other sectors to discuss the

[22] https://www.finextra.com/newsarticle/34941/goldman-sachs-enlists-startup-for-quantum-computing-push

[23] https://www.ibm.com/quantum/business/IDC-MarketScape-2023-Vendor-Assessment.pdf
[24] https://www.mckinsey.com/featured-insights/the-rise-of-quantum-computing
[25] https://ukngt.ukri.org/news/uk-government-publishes-the-national-quantum-strategy
[26] https://qt.eu/about-quantum-flagship/

opportunities and challenges associated with quantum computing in the near-term and long-term future.[27]

Examples of firms already exploiting quantum computing opportunities across the financial services sector

Firm	Activity involving quantum technology
JP Morgan	Developing improved methodologies for financial modelling including option pricing, risk and quantum machine learning.
Goldman Sachs	Investigating quantum computing to gain advantage and unlock efficiencies in pricing sophisticated financial instruments.
Wells Fargo	Using quantum computing to explore how advances in artificial intelligence and quantum computing can help make banking faster, easier, smarter, and safer.
HSBC	Using quantum computing for pricing and portfolio optimisation, to advance its net zero goals, and to mitigate risks, including identifying and addressing fraudulent activity.
Credit Mutual	Started the discovery phase of an engagement to include exploring applicability of quantum computing to banking and insurance use cases and have started workforce development.
ERSTE Group	Using quantum computers to improve the accuracy and speed of complex calculations such as those found in risk management, fraud detection and simulation.
MIZUHO	Major bank from Japan, a member of Quantum Innovation Initiative Consortium (QIIC) by University of Tokyo.
MUFG	Major bank from Japan, a member of Quantum Innovation Initiative Consortium (QIIC) by University of Tokyo.
Caixa Bank	Working with D-Wave Systems to conduct investment portfolio hedging.

[27] https://cra.org/ccc/events/5-year-update-to-the-next-steps-in-quantum-computing-workshop

Ally Financial	Partnered with Multiverse Computing to explore creating investment portfolios using quantum computing.
ING Group	The bank has started exploring quantum technology by way of stress testing possible use cases.

TABLE 2*:* Known quantum programs currently being undertaking by financial firms.

Examples of national / international quantum computing initiatives

Country	Title	Description
USA	National Quantum Initiative ($800m)	The National Quantum Initiative was established by the National Quantum Initiative Act in 2018. This act was amended by the *National Defence Authorization Act* (NDAA) for Fiscal Year (FY) 2022 and by the CHIPS and Science Act of 2022.
UK	UK National Quantum Strategy (10-year strategy, backed by £2.5bn of public funding)	Funding for quantum technologies, new research centres and work on regulating the technology. This funding also includes a quantum skills programme for the UK.
Japan	Quantum Cloud Computing for Industry ($30m)	The Japanese government is to contribute $31.7 million (4.2 billion yen) towards developing shared quantum computing using a business-friendly cloud platform. A quantum computing collective led by the University of Tokyo will receive funding from the Ministry of Economy, Trade and Industry (METI) over the next five years.
China	Estimated government funding of +$15 billion	China published its 14th Five Year Plan, issued in 2017, which includes quantum communication and computing among a list of priority strategic technologies.
France	National Strategy for Quantum Technologies (2021)	€1.8B (US$2.2B) plan, including €1B (US$1.2B) from government
Germany	Quantum Technologies — From Basic Research to Market (2018)	€2B (US$2.4B) to support quantum technology research. 7 current German Research Foundation Clusters of Excellence with a quantum focus; Quantum Alliance of research centres.
India	National Mission on Quantum Technologies & Applications (2020) ($1bn)	Five-year (2020-24), ₹₹80B (US$1.08B) budget, with focus on fundamental science, translational research, technology development, and entrepreneurship in four areas: computing, materials, communications,

		sensing/metrology. Establish 4 research parks and 21 quantum hubs
South Korea	South Korea is running a national competition to identify standardisation of post quantum cryptography, organised by the Quantum Resistant Cryptography Research Centre.	Korean Centre for Quantum Resistant Cryptography's Quantum Resistant Cryptography National Competition (2022-on).

TABLE 3: Support by nation states for quantum technology programs. [28] [29]

[28] https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/quantum%20computing%20funding%20remains%20strong%20but%20talent%20gap%20raises%20concern/quantum-technology-monitor.pdf
[29] Johnny Kung and Muriam Fancy, *A quantum revolution: Report on global policies for quantum technology*, CIFAR

Section 3: Grasping the opportunity

If the financial services sector is to fully realise the potential of quantum technology, it must begin to take practical, tangible steps as a matter of priority.

Action plan for the UK financial services sector

At the sectoral level, it is crucial that the adoption of quantum technology is considered, measured, predictable and safe. This can be achieved through the development and delivery of a sector-wide strategic implementation roadmap enjoying the input and support of all key stakeholders, including financial institutions, regulators, industry associations, and technology providers. Only a collaborative approach will help address the challenges inherent to this technology whilst harnessing its potential.

Establish a Quantum Computing Task Force

Development this implementation roadmap should be the responsibility of a Quantum Implementation Task Force (QITF). QITF should represent all parts of the financial service sector, including regulators and central government. Its objectives should be:

1. Developing a strategic implementation roadmap for the adoption of quantum technology in financial services. This would include making recommendations for the consideration of government and regulators as to an appropriate regulatory framework.
2. Overseeing and being accountable for the delivery of a supporting work programme.
3. Coordinating with international partners to ensure the implementation of this technology is safe and consistent with international standards.
4. Developing strategies that will help build a workforce capable of integrating and utilising this technology.

As part of its role, QITF will also be responsible for monitoring advancements in quantum computing, identifying potential use cases relevant to financial services sector (and relevant subsectors) and responding appropriately. Delivering these objectives whilst developing a strategic roadmap that safely integrates quantum computing solutions into financial services will require the support of a dedicated team with appropriate skills and technical knowledge.

Considering these objectives in greater detail:

Developing a strategic roadmap for the adoption of quantum technology in financial services and overseeing its supporting work programme

As stated above, one of the core deliverables of QITF should be development and delivery of a strategic roadmap supporting the successful adoption of quantum technology in financial services. QITF can achieve this by serving as a platform for knowledge sharing, best practices, and joint research initiatives, enabling stakeholders to stay informed about the latest developments in quantum computing and their implications for the financial services sector.

Supported by appropriate pooled resources and expertise, delivery of this strategic implementation roadmap will be driven by a targeted work programme focused on clear objectives and milestones.

This work programme may consider what quantum initiatives, tools, and applications tailored to the specific needs and challenges of the sector are needed to support its objective.

Develop recommendations regarding an appropriate quantum regulatory framework

In addition to fostering collaboration, QITF will engage with regulators and policymakers in the development of a regulatory framework that supports the adoption of quantum computing in financial services. This includes addressing potential risks associated with quantum computing, such as data privacy and security concerns, as well as ensuring compliance with existing regulations. By actively participating in the development of regulatory guidelines, the industry can help create an environment that fosters innovation while maintaining the stability and integrity of the financial system.

Support the development of a quantum-skilled workforce

The financial sector should invest in education and training programs to develop a skilled workforce capable of harnessing the power of quantum computing in finance. This includes partnering with universities and research institutions to develop specialised curricula and training programs focused on quantum computing and its applications in finance. By cultivating a talent pool with the necessary skills and expertise, the financial services sector can ensure that it is well-positioned to capitalise on the opportunities presented by quantum computing and maintain its competitive edge in the global market. QITF should work with key partners to deliver on these goals.

Action plan for financial services firms

At the firm level, it is crucial that the adoption of quantum technology is considered, measured, predictable and safe.

Invest in quantum computing education and training

Similarly, to fully leverage the potential of quantum computing, financial institutions should invest not only in education and training for their own employees, but also for the future workforce. This includes providing access to resources, workshops, courses on quantum computing fundamentals, as well as industry-specific applications and potential amendments to the national curriculum at all levels.

At an employer level, by investing in employee education and training, organisations can build a strong internal knowledge base and foster a culture of innovation. This will enable financial institutions to better understand the implications of quantum computing for their business and develop strategies for harnessing its potential to drive growth and competitiveness.

Collaborate with quantum computing research institutions and industry partners

Financial institutions should seek collaboration with leading quantum computing research institutions and industry partners to stay at the forefront of this rapidly evolving field. These collaborations can take various forms, such as joint research projects, technology partnerships, or participation in industry consortiums focused on quantum computing.

By collaborating with research institutions and industry partners, financial institutions can gain valuable insights into the latest quantum computing developments and identify potential applications for their business. These partnerships can also facilitate knowledge transfer and accelerate the adoption of quantum computing solutions within the financial services sector.

Identify and prioritise use cases at a firm level

Organisations should identify and prioritise specific use cases for quantum computing within their business. This involves evaluating the potential impact of quantum computing on various aspects of the organisation's operations, such as risk assessment, portfolio management, trading, and cybersecurity.

By prioritising use cases, financial institutions can focus their efforts on the areas where quantum computing is likely to deliver the most significant benefits. This will help organisations strategically plan for the integration of quantum computing solutions and allocate resources effectively.

Develop proof-of-concept projects

Once potential use cases have been identified, UK financial institutions should develop proof-of-concept (PoC) projects to test and validate the feasibility of quantum computing solutions for their business. These PoCs can be conducted in collaboration with technology partners or research institutions and provide valuable insights into the practical implementation of quantum computing.

The development of proof-of-concept projects, an action that can be taken both a sector and firm level, can provide hands-on experience with quantum computing technologies and assess their potential impact on the organisation's operations. This will enable organisations to make informed decisions about the adoption and integration of quantum computing solutions.

Evaluate Infrastructure and Technology Requirements

As UK financial institutions prepare to integrate quantum computing solutions, it is essential to evaluate the infrastructure and technology requirements needed to support these advanced systems. This includes assessing the organisation's existing IT infrastructure, data storage, and connectivity capabilities, as well as identifying any potential gaps or areas for improvement.

By evaluating infrastructure and technology requirements, financial institutions can ensure that they have the necessary foundation in place to support the successful implementation of quantum computing solutions. This will help organisations avoid potential bottlenecks and ensure a smooth transition to quantum-enhanced operations.

Develop a long-term quantum computing strategy

Finally, financial institutions should develop a long-term quantum computing strategy that outlines the organisation's goals and objectives for harnessing the potential of this cutting-edge technology. This strategy should be aligned with the organisation's overall business objectives and should include a roadmap for the integration of quantum computing solutions.

Conclusion

In conclusion, the advent of quantum computing presents a unique opportunity for the UK financial services sector to gain a competitive edge and improve various aspects of its operations. By harnessing the power of quantum computing, financial institutions can enhance their risk analysis, compliance, investment management, data privacy, data management, operations, sales, and pricing strategies, unlocking new opportunities for growth and innovation.

The case studies and data points presented in this paper illustrates the potential of quantum computing in revolutionising the financial services sector. As the technology continues to mature, early adopters of quantum computing stand to gain significant advantages, including increased efficiency, improved decision-making, enhanced security, and the ability to tackle complex problems that are currently unmanageable with classical computing methods.

To fully exploit these opportunities, financial institutions must invest in research, development, and collaboration, both within the financial sector and with external partners, including academia, technology companies, and government agencies. By working together, stakeholders can accelerate the development and adoption of quantum computing technologies, address the challenges that the sector faces, and ensure the long-term success of the UK financial services sector in the global market.

Embracing quantum computing however, also comes with its challenges, such as technical and infrastructure requirements, regulatory concerns, and workforce development.

Financial institutions must invest in research, collaboration, and training to develop the necessary skills and expertise to effectively implement and utilise quantum computing technologies.

As quantum computing technology progresses and becomes more accessible, it is essential for the UK financial services sector to stay ahead of the curve and explore potential applications of this transformative technology. By doing so, UK financial institutions can position themselves at the forefront of the quantum revolution and capitalise on the vast opportunities it presents.

In summary, quantum computing has the potential to redefine the landscape of the financial services sector, providing UK institutions with the tools to address the challenges posed by an increasingly complex and competitive global market. The adoption and integration of quantum computing technologies will be instrumental in shaping the future of the financial services sector, ensuring its continued growth and success in the years to come.

Quantum computing presents a wealth of opportunities for the UK financial services sector, with the potential to revolutionise various aspects of its operations, from risk analysis and compliance to investments and data privacy. The adoption of quantum computing technologies can lead to significant benefits for financial institutions, including increased efficiency, improved decision-making, enhanced security, and the ability to tackle complex problems that are currently unmanageable with classical computing methods.