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Quantum Computing and Its Implications for Theoretical and Applied Economics: From Shor's Algorithm to Models of Uncertainty

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ABSTRACT

This article explores the interdisciplinary interface between quantum computing and economic theory, with a particular emphasis on how foundational concepts from quantum mechanics reshape core methodological and epistemological assumptions in economics. Drawing on a comprehensive bibliographic methodology, the study synthesizes contributions from quantum physics, computational theory, and economic modeling to trace the impact of quantum logic -especially principles such as superposition, entanglement, and measurement irreversibility- on both theoretical constructs and applied frameworks. Particular attention is given to emblematic algorithms (e.g., Shor's and Grover's) as case studies for illustrating computational discontinuities in fields such as cryptographic trust, portfolio optimization, and decision-making under uncertainty. The article also surveys recent developments in quantum machine learning and quantum-inspired models relevant to economic forecasting and adaptive policy design. Ethical and distributional concerns are critically addressed, especially in relation to the asymmetric global access to quantum resources. By mapping this emerging field through a structured review of cross-disciplinary literature, the paper offers a conceptual framework for understanding how quantum technologies may influence future research in financial economics, risk theory, and the modeling of complex systems operating under deep informational constraints.

Keywords: *Shor's-Grover's Algorithms, Quantum Computing/Logic, Superposition, Decision Theory, Financial Technology* ***JEL Codes:*** *C63, D80, E61*

INTRODUCTION

Historically, the evolution of information technologies has profoundly influenced both the theory and practice of economic science, from econometrics and financial analysis to game theory and microeconomic behavior. Today, the emergence of quantum computing does not merely represent a technological advancement, but potentially a paradigmatic leap in the very logic through which economic phenomena are approached, understood, analyzed, and predicted.

Quantum computing, being a radically different approach to information processing, appears capable of transcending the limitations of classical computational models, shaping a new framework of inquiry (Nielsen & Chuang, 2010). Although the technology remains in an early stage of development, its promise of a fundamental upgrade in processing capabilities for specific classes of problems renders it imperative to reflect in a timely manner on its potential impacts in fields characterized by high degrees of uncertainty, such as economics (Arute et al., 2019).

From cryptography and game theory to dynamic risk valuation models, Quantum Computing – founded on the principles of quantum mechanics (Ladd et al., 2010) – has the potential to reshape core tools and assumptions of economic thought. At the same time, it opens new horizons in information processing, the treatment of uncertainty, and the understanding of complexity (Preskill, 2018; Griffiths & Schroeter, 2018). Information, whether measured in bits or qubits, is physically realized through systems such as electronic circuits, optical fibers, or superconducting materials. The reduction of entropy in a quantum system is directly related to the energy efficiency of computational processes, according to Landauer's thermodynamic limit: $E = kT \cdot \ln(2)$ per bit of information.

The primary aim of this paper is to outline an interpretive and analytical framework for the encounter between economic thought and the quantum era, highlighting both the opportunities and challenges arising from this emerging convergence of technology and social science. The economic literature approaches quantum perspectives with caution, a stance that has contributed to the persistence of a notable research gap. This gap concerns the systematic study of quantum logic at the level of methodology and epistemology within the economic sciences, limiting the integration of quantum mechanical concepts into the theoretical and analytical foundations of economic thought (Baaquie, 2007; Haven & Khrennikov, 2013).

At a functional/technical (first) level, quantum computing can influence applied economic analysis by accelerating complex computations, reshaping the cryptographic security of financial transactions, and enabling optimization in problems that have so far remained computationally intractable. At a deeper conceptual/philosophical (second) level, it raises fundamental questions concerning the nature of information, prediction, rationality, and uncertainty, issues that lie at the core of economic theory.

The methodological approach consists of: a literature review of contemporary research in the fields of quantum information science and economics; a theoretical investigation of the conceptual bridges between the two domains, aimed at identifying points of interaction; and an analysis of selected cases of economic significance.

Core concepts that run throughout the paper and form the foundation of the analysis include:

Quantum Computing, understood as an approach grounded in the principles of quantum mechanics, utilizing qubits, superposition, and entanglement for information processing.

Theoretical Economics, referring to the branch of economic science focused on the formulation of abstract mathematical models to understand economic phenomena.

Applied Economics, denoting the use of theoretical models and analytical tools to solve economic problems, including those in political economy, finance, and data analysis.

Shor's Algorithm, a quantum algorithm for integer factorization that poses a threat to cryptographic systems based on the presumed intractability of the factorization problem.

THEORETICAL BACKGROUND: PRINCIPLES OF QUANTUM COMPUTING

The theoretical foundation of quantum computing is grounded in the physical theory of quantum mechanics and introduces a radically different approach to the representation, processing, and utilization of information. Instead of relying on binary bits, it employs qubits[1], which can exist in

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[1] Quantum computers, unlike classical ones that use binary digits (bits) 0 and 1, rely on quantum bits, known as qubits. A qubit can exist in a superposition of the states 0 and 1 – that is, it can

superpositions of multiple states simultaneously and can become non-locally entangled with one another. This enables the parallel processing of alternative solutions and the achievement of computational performance that surpasses the limits of classical architectures (Griffiths & Schroeter, 2018).

Quantum Mechanical Foundations

At the core of quantum computing lie four critical concepts: superposition, entanglement, the irreversibility of measurement, and the probabilistic nature of information. These concepts cannot be described in terms of causality, locality, or complete knowledge of a system's state -as defined in the Newtonian or Cartesian paradigm- but instead constitute the epistemological foundations of the quantum computational architecture.

Superposition allows a qubit to exist in a linear combination of the states $|0\rangle$ and $|1\rangle$, enabling it to encode multiple values simultaneously. This property exponentially expands the computational space compared to classical bits, making it possible to parallelize processing and explore complex states through a single operation (Nielsen & Chuang, 2010; Preskill, 2018).

Entanglement is a distinctly quantum phenomenon in which the state of one qubit is inseparably dependent on the state of another, regardless of physical distance. Entanglement enables the development of interdependent systems with non-local correlations, enhancing efficiency in representing and solving large-scale problems (Bravyi, Gambetta, & Temme, 2022).

The **irreversibility of measurement** represents a fundamental departure from classical logic: when a qubit is measured, its superposition collapses to a definite value ($|0\rangle$ or $|1\rangle$), destroying the original probability wave. This process is irreversible and makes the timing and method of measurement critical during the execution of a quantum computation (Griffiths & Schroeter, 2018; Roffe, 2019).

The **probabilistic nature of information** implies that the outcomes of quantum computations are not deterministic but are expressed as probability distributions. Information is extracted statistically through repeated measurements, a fact that redefines the notions of accuracy and reliability in computational design (Biamonte et al., 2017; Schuld & Petruccione, 2021).

Taken together, these four principles constitute not only the technical foundations of quantum information science but also an alternative interpretive paradigm for processing and modeling complex systems – with significant implications for decision theory, economic modeling, and information processing under uncertainty.

The Qubit and the Representation of Information

The fundamental unit of information in quantum computing is the qubit (quantum bit), which represents a physical and mathematical generalization of the classical bit. Unlike the bit, which can

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simultaneously represent combinations of these values. As a result, quantum computers can process significantly more information than classical computers for certain types of problems. Furthermore, when two or more qubits are 'entangled,' the state of one depends on the state of the other, even if they are physically distant from each other. These properties enable complex, parallelized computational processes, with capabilities that exceed the limits of today's classical computers. Despite their potential, current quantum computers remain in an experimental phase and face major challenges, such as noise (random interference that distorts the quantum state of a qubit) and decoherence (when a qubit loses its quantum coherence and behaves like a classical bit). These issues lead to unreliable results, necessitate error correction techniques, and impose strict time constraints. If an algorithm is not completed in time, the qubit loses its quantum state and effectively becomes a classical bit, causing the final result to lose its accuracy or meaning.

exist only in one of two states, 0 or 1, the qubit can exist in a superposition of these states, described by a state vector of the form:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle, \text{ where } |\alpha|^2 + |\beta|^2 = 1$$

This representation allows the qubit to exist simultaneously in multiple possible states, rapidly increasing the volume of processable information as the number of qubits grows exponentially (Nielsen & Chuang, 2010).

A useful geometric representation of a qubit's state is provided by the so-called Bloch sphere, where each pure qubit state corresponds to a point on the surface of the unit sphere in $\mathbb{R}^3$. The ›basis states $|0\rangle$ and $|1\rangle$ are represented at the poles of the sphere, while their superpositions are distributed across other points on the surface.

This representation offers not only an intuitive understanding of quantum states but also a practical depiction of quantum logic operations as rotations on the sphere (Schuld & Petruccione, 2021).

Quantum gates are fundamental units of information processing, analogous to logic gates in classical computing. However, quantum gates are reversible linear operators (unitary operators) applied to qubits, transforming their state. Notable examples include the Hadamard (H), Pauli (X, Y, Z), Phase (S, T) gates, and multi-qubit gates such as CNOT and Toffoli. The combinatorial application of such gates enables the construction of complex circuits for implementing algorithms like Shor’s and Grover’s (Rieffel & Polak, 2011).

Qubit technologies such as superconducting circuits (IBM Q), trapped ions (IonQ), and topological qubits (Microsoft) delineate the practical possibilities for implementing quantum information. As such, they shape the boundaries of computational performativity and critically influence how information is reproduced, activated, and integrated into economic processes.

Information representation in quantum computing is not static, but multidimensional, continuous, and dynamically evolving, with operations on qubits taking place within an inner Hilbert space where the computational process unfolds.

Quantum Algorithms

Quantum computing is also characterized by the development of new algorithmic frameworks that solve problems with exponential or quadratic advantages over classical algorithms. The most well-known quantum algorithms include Shor’s and Grover’s algorithms, as well as more recent hybrid approaches such as the Quantum Approximate Optimization Algorithm (QAOA) and the Variational Quantum Eigensolver (VQE), both of which are particularly significant for tackling optimization problems.

Shor’s algorithm (Shor, 1997) provides exponential speedup in the factorization of integers, a problem that underpins the computational hardness of asymmetric cryptographic protocols such as RSA. This algorithm solves the factorization problem in polynomial time by employing quantum period-finding as its core technique. Its theoretical efficiency, combined with the vulnerability it exposes in existing cryptographic security, has triggered significant efforts in the field of post-quantum cryptography (Chen et al., 2016).

Grover’s algorithm (Grover, 1996) accelerates unstructured search in databases by reducing the search time from $O(n)$ to $O(\sqrt{n})$[2]. Although it does not provide exponential speedup, it offers a quadratic

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[2] From an engineering perspective, Grover’s algorithm offers a square-root speedup in the search of unstructured data. This feature renders it particularly applicable to the analysis of large-scale

improvement, which is significant for applications such as searching through financial data, localized forecasting within market subsets, and evaluating logical conditions (Montanaro, 2016).

Recently, hybrid algorithms such as QAOA (Farhi et al., 2014) and VQE (Peruzzo et al., 2014) have attracted considerable interest, as they combine classical and quantum computing. QAOA aims to find approximate solutions to hard optimization problems, such as resource allocation, logistics, or portfolio management. VQE, on the other hand, is designed to compute eigenvalues of complex observables and finds applications in economic models based on energy-like cost functions (Bharti et al., 2022).

All of the above have shaped a new computational paradigm that expands the boundaries of both theoretical and applied algorithmic thinking.

Computational Complexity and Quantum Advantage

The evaluation of quantum computing extends to the systematic comparison of its computational complexity with that of classical computational paradigms. At the core of this comparison lie the complexity classes P, NP, and BQP[3].

The class BQP (Bounded-Error Quantum Polynomial Time) defines the set of problems that can be solved by a quantum computer in polynomial time with an error probability of less than 1/3. Although P ⊆ BQP, it is not known whether BQP ⊆ NP or whether the two sets intersect. Significant theoretical studies suggest that problems such as integer factorization (Shor’s algorithm) lie in BQP but not in P, indicating a potential advantage in selected categories of problems (Bernstein & Vazirani, 1997; Watrous, 2009).

The concept of quantum advantage or quantum supremacy refers to the ability of a quantum system to solve a computational problem faster or more efficiently than any known classical system. In 2019, Google announced that its 53-qubit processor, Sycamore, successfully performed a specially designed sampling task in 200 seconds, which -according to their estimates- would take 10,000 years to complete on a classical supercomputer (Arute et al., 2019). This claim marked a milestone, although it received criticism regarding the practical relevance of the problem used (Pednault et al., 2019).

Similarly, IBM has focused on building scalable architectures, making significant progress in error-corrected logical qubits and modular systems. In December 2023, it announced its roadmap toward reaching 100,000 logical qubits by 2033, emphasizing a gradual transition from the NISQ (Noisy Intermediate-Scale Quantum) era to scalable quantum computing (IBM, 2023). At the same time, companies such as IonQ and Rigetti[4] are developing specialized platforms for quantum cloud computing, enhancing the accessibility of these technologies.

In contrast to classical computational systems, which return deterministic values, quantum systems compute probability amplitudes and yield outcomes only upon measurement. Measurement does not reveal a "hidden" value but induces the collapse of the superposition into one of the possible states – each time potentially a different one (Barad, 2007).

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econometric databases, where efficient information retrieval is crucial in the absence of predefined structure.

[3] The complexity classes P, NP, and BQP categorize problems based on how efficiently they can be solved: P includes problems solvable in polynomial time by a classical computer; NP includes problems whose solutions can be verified in polynomial time; and BQP includes problems that can be solved in polynomial time by a quantum computer with a success probability greater than 2/3.

[4] IonQ and Rigetti are cutting-edge technology companies operating in the field of quantum computing, with a focus on hardware development and cloud-based platforms.

A characteristic example is the application of the Hadamard gate to a qubit, which produces an equal-probability superposition of the 0 and 1 states. In an economic model, this would correspond to a condition of intrinsic uncertainty – not due to ignorance of the system's actual state, but because such a state does not exist prior to the act of observation. This marks a radically different form of uncertainty, more closely aligned with *Knightian uncertainty* than with classical statistical variance. Within this framework, information is not merely something to be revealed – it is something that is enacted. Quantum information processing does not simply bring computational acceleration; it foregrounds an epistemological shift in which the very notions of reproduction, measurement, and valuation of information take on a performative character.

Although the full exploitation of quantum advantage in general computational problems remains an open challenge, the rapid advancement of systems and the theoretical foundation provided by BQP point to an emerging post-paradigmatic space, in which quantum systems may operate either complementarily or competitively with classical infrastructures.

COMPUTATION AS A PILLAR OF ECONOMIC SCIENCE

Traditionally oriented toward the analysis of human behavior and the construction of theoretical models, economic science has been radically transformed over the past 70 years thanks to advances in computational technology. From the numerical simulation of simple models to the widespread use of machine learning algorithms in real-time economic forecasting (Desai, 2023), computation has evolved into a fundamental tool for the production and validation of economic knowledge (Babii, Ghysels, Striaukas, 2023).

To a large extent, computational tools have been integrated into economics, both for theoretical modeling and for empirical analysis. The development of game theory, computational general equilibrium, dynamic stochastic general equilibrium (DSGE) models, macroeconomic forecasting, and econometrics has been made possible by advances in computational power (Judd, 1997; Heer & Maußner, 2011; Rothe, 2023). Computation, therefore, is not an external instrument but a structural component of modern economic thought. This implies that any profound shift in the nature of computational power – such as the one proposed today by quantum computing, has the potential to transform the very foundations of economic theory.

The historical evolution of computation in modern economics can be assumed to include the following periods and trends:

a) 1950–1980: The era of numerical models and early simulations on mainframe computers. The DSGE (Dynamic Stochastic General Equilibrium) framework begins to gain traction due to the feasibility of numerical solutions (Damiani, 2025).

b) 1980–2000: The spread of personal computers and the advancement of computational tools (e.g., MATLAB, STATA) lead to the widespread use of econometric analyses and empirical modeling (Ooms, 2006; Cameron, 2014).

c) 2000–present: The explosion of data (big data), deep learning techniques, and cloud computing infrastructures enables the processing of massive datasets, real-time economic variables, and multi-factor models (Seidou Sanda, 2023).

Modern economic analysis increasingly relies on computational models and algorithms to understand and forecast the dynamics of complex systems. In this context, the study of markets such as energy, telecommunications, and financial products requires multi-factor modeling involving multiple agents interacting with adaptive behaviors (Tesfatsion & Judd, 2006). These multi-level models enable the representation of non-linear relationships and the simulation of strategic choices made by economic actors.

At the same time, the rapid advancement of technology has made algorithmic trading a core operational tool in financial markets. Transactions are now executed on millisecond timescales, driven by automated algorithms and real-time analysis, supported by advanced market microstructure models

(Lehalle & Laruelle, 2013). The speed and computational efficiency of these systems make the application of advanced optimization and forecasting techniques critically important (Zhang et al., 2020).

The computational power of modern cloud and high-performance computing (HPC) infrastructures supports increasingly complex policy simulations. So-called 'what-if' scenarios allow researchers and policymakers to evaluate the potential impacts of different macroeconomic interventions, incorporating nonlinearities and feedback loops across sectors (Fagiolo & Roventini, 2017).

Finally, an increasingly widespread tool is the Agent-Based Modeling (ABM) approach, in which multiple agents with bounded rationality and the capacity for interaction give rise to emergent phenomena that are not readily captured by classical models (Farmer & Foley, 2009). ABMs offer both a new theoretical and practical framework for studying behavioral and evolutionary economics, leveraging the power of simulation and computational complexity.

It appears that the computational mode of thinking – simulation, parameterization, computational complexity – has become the new 'language' of economics. Not merely as a tool, but as a conceptual shift: from static, analytical solutions to dynamic, evolutionary approaches grounded in computation. This foundation raises a legitimate question, if economic thought has already integrated computation as an integral part of its methodology, then its future trajectory may well extend from the classical to the quantum.

APPLICATIONS OF COMPUTATIONAL POWER IN ECONOMIC DECISION-MAKING

Quantum computing is not merely a faster version of existing classical computational models; rather, it offers a new paradigmatic framework for addressing complex, stochastic, and dynamic problems in economic science. Timely understanding and adaptation of these tools is crucial for both researchers and economic policy-makers. Key components of this framework include:

Computational Power in Optimization Problems

Many economic problems (such as resource allocation, portfolio design, price auctions, and dynamic pricing) are formulated as complex optimization problems. As the number of variables increases, these problems become computationally intractable for classical computers. This limitation can be overcome through quantum computing, which, by leveraging phenomena such as superposition and entanglement, is capable of simultaneously exploring multiple options and providing exponentially faster solutions for certain classes of problems (Farhi, Goldstone, Gutmann, 2014).

Applications Include:

- Optimization of supply chain flows
- Real-time capital allocation
- Arbitrage detection in high-frequency markets

Analysis of Large Volumes of Economic Data

Analysis of vast volumes of data -such as those arising from financial transactions, social networks, or real-time sensors tracking economic activity- is computationally intensive.

Quantum machine learning algorithms (such as Quantum Support Vector Machines and Quantum PCA) promise significant speedups in pattern extraction and predictive tasks, including credit risk analysis and macroeconomic trend forecasting (Biamonte et al., 2017).

Moreover, quantum circuits, due to the absence of thermal losses in superconducting environments, offer computational solutions with exceptionally low energy consumption. The development of scalable and fault-tolerant quantum systems is expected to radically reduce the energy footprint of computational infrastructures – especially when compared to the energy-intensive data centers of classical computing.

Implications for the Security of the Financial System

Quantum computing poses a threat to current cryptographic standards upon which nearly all economic systems rely (banks, exchanges, and blockchain networks). Shor's decryption algorithm, for instance, could break asymmetric protocols such as RSA, thereby undermining trust in electronic transactions and cryptocurrencies (Shor, 1997).

Decision Theory and Behavior

Some researchers argue that quantum logic may offer an alternative methodological foundation for decision theory under uncertainty and for economic psychology, particularly in situations where deviations from the rational model are observed, such as violations of the Sure-Thing Principle (Haven & Khrennikov, 2009, 2013).

Delimitation, Performativity, and Verification Challenges

From a technical standpoint, it is crucial to highlight the limitations of current quantum technology, which act as barriers to the immediate realization of the economic and epistemic visions articulated in this paper. Issues such as decoherence, measurement errors, and the pressing need for effective quantum error correction mechanisms underscore the practical obstacles involved in transitioning to large-scale quantum computational models (Preskill, 2018).

The implementations developed by leading actors in the field -such as IBM, Google, and Quantinuum- remain constrained within the NISQ (Noisy Intermediate-Scale Quantum) paradigm. Consequently, references to performative transformations of economic practice through quantum infrastructure must be articulated with caution and within clearly defined technological boundaries (Preskill, 2018; Arute, et al. 2019).

DISCUSSION

The dynamic entry of quantum computing into the domain of economics raises questions and possibilities that go beyond the instrumental level. From the reformulation of economic rationality to the collapse of traditional cryptographic systems, and from methodological shifts in modeling to ethical and institutional dilemmas, the transition from classical to quantum systems is not merely technological – it is conceptual, epistemological, and potentially political.

Quantum Computing and Economic Modeling under Uncertainty

Economic modeling under uncertainty constitutes a cornerstone of modern macroeconomic and microeconomic theory, particularly through dynamic general equilibrium models (DSGE), agent-based modeling (ABM), and complex network-based interaction models. These frameworks seek to capture agent behavior under conditions of informational incompleteness, nonlinearity, and stochastic dynamics. However, as the complexity of economic systems grows exponentially, classical computational methods prove increasingly limited – both in terms of efficiency and in their ability to represent the very nature of uncertainty (Orrell, 2018).

Quantum computing reintroduces the discussion of uncertainty at the very foundation of computation. Unlike classical stochasticity, quantum models rely on the principles of superposition and quantum probability, which do not merely assign uncertainty to values, but embody a simultaneous multiplicity of states (Schuld & Petruccione, 2018). This logic enables a more natural integration of institutional, behavioral, and informational uncertainty into economic models.

Within this context, quantum algorithms such as the Quantum Approximate Optimization Algorithm (QAOA) and Grover's algorithm offer the potential to solve policy selection, matching, and equilibrium problems with exponential speedup compared to classical methods (Rebentrost, Gupt, & Bromley, 2020). At the same time, quantum annealing platforms such as D-Wave can function as 'quantum simulators' for reproducing the behavior of complex agent-based models, even when no analytical solution is available (Otterbach et al., 2017).

The transition from static and deterministic DSGE models to more adaptive, stochastic, and multi-level systems represents a profound shift in economic thought. Within this new horizon, quantum computing is not merely a more powerful simulation tool; it functions as a transformative mechanism that reconfigures the very framework of uncertainty, revealing new conceptual and methodological possibilities for economic analysis (Baaquie, 2007; Woerner & Egger, 2019).

Rethinking Rationality: From Homo Economicus to the Quantum Player

The concept of rationality constitutes a fundamental pillar of neoclassical economic theory and policy, with the Homo Economicus embodying a subject driven by self-interest, endowed with stable preferences and the capacity for optimization under conditions of information and computational power (Gazetas & Aznaouridis, 2025). However, empirical research in behavioral economics and decision theory has documented the existence of preference instability, contradictory choices, and cognitive limitations (Kahneman, 2011). These limitations gave rise to Simon's theory of 'bounded rationality,' which, nonetheless, remains situated within the framework of classical logic.

Quantum theory offers an alternative cognitive paradigm. Rather than simply adding noise or error to preferences, it proposes an entirely different mathematical and conceptual foundation: preferences are not expressions of a fixed vector, but superposition states that collapse into specific choices only during the process of observation or decision-making (Busemeyer & Bruza, 2012). This model accounts for phenomena such as contradictory responses, framing effects, and intransitive preferences – phenomena that classical models struggle to explain.

The transition from deterministic behavior to probabilistic cognitive states redefines not only the notion of rationality, but also what constitutes a 'logical' choice. In quantum frameworks, the 'player' can simultaneously occupy multiple cognitive states, with probabilities connected through entangled structures rather than conventional distributions (Haven & Khrennikov, 2013). The mechanism of observation – whether in the form of questioning, information exposure, or environmental context – fundamentally influences the final decision, introducing a new kind of endogenous uncertainty.

The implications of game theory in the quantum context are particularly significant. In the classical approach, a player's strategy is defined by the maximization of expected utility, taking into account the strategies of other players. In the quantum formulation, however, strategies are represented by operators acting on quantum states, and the concept of equilibrium -such as the Nash equilibrium- is redefined in terms of quantum characteristics, including compatibility and correlations between states (Iqbal & Abbott, 2009). At the same time, in utility models, value assessment is no longer a simple linear composition of probabilities, but emerges from the internal dynamics and interactions among potential outcomes.

Political economy is not immune to these shifts. If the 'citizen' or 'economic agent' is no longer a subject with stable preferences, then the meaning of policy intervention, social choice, and regulatory frameworks is also transformed. Decision-making ceases to be a point in a predefined choice set and becomes a process of collapsing a space of possible multiplicities. Economic policy must now account not only for incentives, but also for the architecture of the cognitive state in which agents operate (Pothos & Busemeyer, 2013).

Cryptography and Financial Security in the Quantum Realm

The emergence of quantum computing capability brings about fundamental transformations in the way digital transaction security is approached. Shor's renowned algorithmic proposal (1994), which solves integer factorization and discrete logarithm problems in polynomial time, signals an impending collapse of most classical asymmetric cryptosystems such as RSA, ElGamal, and ECC. This critical development has serious implications for financial infrastructures, where the security of authentication and signatures relies on these methods.

Recognizing the threat, an emerging field of post-quantum cryptography (PQC) has taken shape, aiming to develop algorithms resilient to attacks by quantum computers. Since the launch of the NIST initiative (Chen et al., 2016), new solutions have been proposed, such as lattice-based cryptosystems (e.g., Kyber, Dilithium) – which promise to preserve the confidentiality and integrity of communications even in the era of quantum computational power.

However, a mere substitution of algorithms is not sufficient. The transition to a quantum-secure financial ecosystem requires a radical restructuring of the digital infrastructure underlying transactions, including blockchain technologies, digital currency systems, and interbank clearing mechanisms. Despite the apparent integrity of distributed ledger networks, many existing implementations rely on cryptographic signatures that are vulnerable to future quantum attacks (Aggarwal et al., 2017).

The temporal asymmetry between the maturation of the threat (the gradual progress toward a universally practical quantum computer) and the slow institutional response constitutes a critical challenge. On one hand, adversaries can already implement 'harvest now, decrypt later' strategies, recording sensitive data to decrypt once the technology allows. On the other hand, adopting new protocols requires time, resources, and systemic harmonization on a global scale.

This gap raises the question of whether technology can continue to guarantee trust when its very cryptographic foundation is under threat. The answer is far from self-evident. On the contrary, it reveals the need for multi-layered institutional fortification that does not rely solely on computational assumptions. A combination of post-quantum algorithms, controlled revocation-validation mechanisms, and potentially quantum key distribution (QKD) could help establish a new, resilient framework of trust (Mosca, 2018). From this perspective, the technological transition must be holistic and anticipatory, rather than reactive.

Applied Practices, Methodological Instruments, and Ethical Dilemmas

Quantum technology, transcending its theoretical framework, has begun to acquire a practical dimension through platforms and tools that enable experimentation in applied domains of the economic sector. Environments such as IBM's Qiskit and D-Wave's Leap SDK[5], offer capabilities for the development and simulation of quantum algorithms, providing access to quantum backends (gate-based or quantum annealing) for real computations (Cross et al., 2017; D-Wave Systems, 2023).

New horizons are thus opening for economic modeling. Scenarios such as demand forecasting, credit scoring, and dynamic pricing can be reformulated as optimization or classification problems, leveraging quantum properties such as superposition and entanglement. Already, studies have shown

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[5] These are tools that allow programs to be written and executed on quantum computers. IBM's Qiskit is an open-source software library written in Python, which runs on IBM's real quantum computers via the cloud. It can be considered a toolkit for building a complex project from the ground up. D-Wave's Leap SDK is a cloud-based platform that enables the development of programs designed to solve optimization problems – i.e., problems where the goal is to find the best solution among many alternatives.

that, on limited datasets, hybrid (quantum-classical) models can compete with conventional deep learning systems in terms of both accuracy and speed (Havlíček et al., 2019; Orús et al., 2019).

Researchers are gaining the ability to test experimental algorithms or applications for quantum computers on real-world economic problems, such as investment strategies and risk management. This allows them to explore whether such solutions could attain practical value in the future, even though full quantum advantage in these domains remains a distant goal. The significance here is not merely technical, but also methodological and ethical in nature.

One of the critical issues is transparency. In the field of Explainable AI (XAI)[6], the transition to quantum systems complicates interpretability. Computational states are no longer merely weight matrices or decision graphs, but combinations of wavefunctions – something that directly challenges human understanding of decisions (Gili et al., 2023). This raises the question: how do we explain a credit prediction when it results from a quantum entanglement of states?[7]

Moreover, quantum economic power[8] is not equally distributed. The construction and access to quantum systems require vast resources, further reinforcing existing geopolitical and economic inequalities (Zeng et al., 2022). The question becomes more pressing: who has access to quantum computational capabilities for economic forecasting and analysis? And what does "quantum influence" mean when only a handful of platforms can affect global markets through opaque, black-box infrastructures?

The era of quantum technology does not merely introduce new technical capabilities; it also raises critical issues of trust, interpretability, and institutional fairness. The role of the scientific community is to ensure that quantum applications do not become opaque instruments of power, but rather open and accountable methods deployed for the public good.

CONCLUSIONS AND SCIENTIFIC OUTLOOK

Quantum computing is not merely an additional technological tool added to the arsenal of economic analysis; it represents a profound challenge to the very conceptual and computational framework of the discipline. The shift from classical deterministic logic to a domain governed by superposition, entanglement, measurement irreversibility, and non-locality makes it evident that the foundational principles of traditional economic theory -such as stable rationality, predictability, and local causality- are no longer sufficient. Economic reasoning, as shaped by the mathematization of the 20th century and the rise of data-driven statistical approaches, is currently undergoing an epistemological reconfiguration.

This emerging reality calls for deep interdisciplinary collaboration. Articulating and understanding the concept of a "quantum economy" requires the joint efforts of physicists, economists, computer scientists, and philosophers of science. Questions such as: What is information? How choice is defined when alternatives are not discrete but exist in superposition? What does rationality mean when the very act of measurement affects the outcome? These cannot

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[6] It is a form of artificial intelligence that provides not only answers, but also explanations.

[7] In other words, how can we explain a credit approval decision when it is not based on simple, understandable rules, but on complex quantum relationships between data?

[8] The potential to transform the economy and gain strategic advantage through the utilization of quantum technological capabilities.

be answered unidimensionally. Rather, they demand philosophical reflection, computational modeling, and physical grounding.

The development of research infrastructures that transcend the narrow boundaries of individual disciplines is of vital importance. Quantum economics labs – spaces where researchers from diverse fields can collaborate using shared infrastructures and a common conceptual language – may constitute a turning point in scientific inquiry. Illustrative issues these interdisciplinary teams are called to explore include:

- How quantum decision-making models can be implemented in real-time economic environments.
- What role quantum uncertainty plays in markets, and how it reshapes risk theory.
- What kind of institutional and political framework can be envisioned in a post-classical era of economic computability.

At the same time, it is essential to develop politically oriented, policy-focused research programs that examine the social, institutional, and ethical implications of introducing quantum technologies into the economic domain. Issues such as the unequal distribution of quantum computational power, the black-box nature of infrastructural systems, and the limited interpretability of decisions make democratic accountability and institutional transparency all the more urgent.

Ultimately, quantum computing is not merely a new form of data processing; it constitutes a new epistemological regime. Its penetration into economic thought and practice compels us to re-signify fundamental concepts such as what it means to “compute,” “predict,” or “choose.” If we rise to this challenge with critical insight, interdisciplinary collaboration, and institutional vigilance, we may find ourselves before a historical opportunity to redefine economic reasoning on the basis of the most fundamental principles of physical reality.

SUGGESTED DIRECTIONS FOR FUTURE RESEARCH

Establishment of Quantum Economics Laboratories:

- Pilot development of hybrid models (classical and quantum) for financial forecasting.
- Experimental research on decision-making under multi-state uncertainty environments.

Investigation of Epistemological Shifts:

- Comparative analysis between classical and quantum rationality.
- Ontological and epistemological grounding of information within economic frameworks.

Policy Studies and Social Impact Assessments:

- Quantification of the unequal distribution of access to quantum computational power.
- Governance scenarios for quantum technology in global economic networks.

Education and Dissemination Tools:

- Development of open-access educational resources in quantum economics.
- Organization of collaborative or competitive technological workshops (hackathons) focusing not only on technical innovation but also on ethical foresight.

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