STRATOS
Research

A New Era For Financial Markets: The Advent Of Quantum Finance

Scientific innovation is constantly evolving and so will financial markets applications: throw away Artificial Intelligence, Quantum Finance is Coming!

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November 24, 2025

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1. From binary bits to qubits: a generational leap

Quantum computing represents an emerging field of research that aims to exploit and develop knowledge from quantum mechanics to solve problems too complex for current computers based on binary bits. **Bits** are the smallest unit of data in classical computing, representing a single value of either 0 or 1. Various combinations of bits are used to represent larger numbers; for example, the largest number achievable with 8 bits is 255. These inputs are fundamental as they determine the information processed by computing devices.

However, today's financial world is getting constantly more complex, characterized by vast datasets, intricate risk models and countless real-time global transactions, hence classical computing and even cutting-edge *Artificial Intelligence* are pushed to their functioning limits. **Quantum finance**, the integration of quantum computing principles into financial systems, comes as an actual game-changer, offering a future of quicker and more precise computing performances.

AI-based systems have transformed finance by enabling sophisticated data analysis, predictive modeling and automated decision-making. *Machine learning* algorithms detect patterns, manage risks and optimize trading strategies with impressive efficiency. However, they remain constrained by the limitations of classical computing, particularly when solving complex optimization problems and processing huge amounts of data in real-time.

Therefore, quantum finance allows for a fundamental shift by leveraging the principles of quantum mechanics to process information in new, more efficient ways. While classical computers use bits, quantum computers use **quantum bits** or **qubits**. A qubit's power consists of its ability to exist in a state of **superposition**, representing both 0 and 1 simultaneously. This sounds extremely appealing to financial analysts exploring countless potential market scenarios all at once, rather than sequentially. For financial problems with a vast number of variables, such as optimizations of particularly complex portfolios, a classical computer must evaluate each potential combination one by one. A quantum computer, however, can leverage superposition to explore many of these combinations simultaneously, offering the potential for exponential speedups.

Another critical quantum phenomenon is **quantum entanglement**, a deep connection between qubits where the state of one instantly influences another, regardless of physical distance. This correlation allows quantum computers to handle interconnected variables in a highly efficient way, much like modeling the complex, non-local correlations seen in global financial markets where an event in one region can instantly impact assets worldwide.

Two of the most interesting applications of quantum principles to financial markets are *quantum Monte Carlo simulations* and *quantum random walks*.

1.1. Quantum Monte Carlo simulations: upgrading financial crystal balls

A **Monte Carlo simulation** consists of statistical technique used to model the probability of different outcomes in a *stochastic process*, namely a collection of random variables. These outcomes might often result particularly difficult to compute given the complexity of the process itself. It is thus a computational algorithm that relies on repeated random sampling to obtain numerical results.
The essential idea is to define a domain of possible inputs, generate inputs randomly from a probability distribution over the domain, perform a deterministic computation on the inputs and finally average the results. In finance, this translates to simulating thousands or even millions of potential future paths for market variables in order to precisely forecast scenarios. Among various applications, *option pricing* and **VaR** (i.e. **Value at Risk**) estimation for a portfolio are commonly known.
In statistics, the expected value of a random variable X in the continuous time, with realizations x and probability density $p(X)$, is given by:

$$E[X] = \int xp(X)dx \tag{1}$$

A Monte Carlo estimator for this integral is:

$$E[X] \approx \frac{1}{N}\sum_{i=1}^{N} x_i \tag{2}$$

where x_i are independent samples drawn from X and N is the total number of replications. The *central limit theorem* tells us that the estimation error converges to $1/\sqrt{N}$. Hence, to halve the error, we would need to quadruple the number of N. This means that, in order to achieve sufficient accuracy, we could require millions of simulations, consuming much time and energy on classical computers, often taking hours or even days for the most intricate cases.
The **Quantum Monte Carlo (QMC)** algorithm rewrites this scaling law. While a classical computer must evaluate each path sequentially, a quantum computer leverages superposition to evaluate all paths simultaneously. The process begins by loading the probability distribution $p(X)$ into a quantum state:

$$|\psi\rangle = \sqrt{p(x_i)}|i\rangle \tag{3}$$

A quantum circuit then computes the outcome into the amplitude of an **ancilla qubit**, namely an extra-qubit used for auxiliary functions such as storing an intermediate result. The key innovation is represented by the **amplitude estimation**, a quantum algorithm that acts like more powerful version of the statistical expected value calculation. It allows the expected value to be read not by averaging individual results, but by using quantum interference to extract it directly from the wave pattern of the superposed states.
The result is an incredible *quadratic speedup*, reducing the error scaling to $1/N$. Where a classical simulation might need 1,000,000 replications, a quantum algorithm could achieve comparable precision with only 1,000. This also allows to transform previously unsolvable problems into solvable ones. Of course, aforementioned financial applications could definitely benefit from this new dynamic speedup.

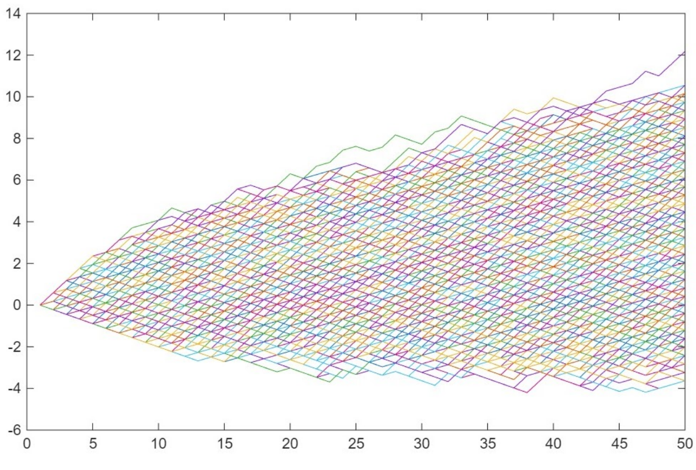

Figure 1: Countless paths of a classical Monte Carlo simulation plotted in Matlab

1.2. Quantum random walks: modeling the "herding" behaviour of financial markets

The **random walk hypothesis** is fundamental to financial economics, stating that asset returns are **IIDs** (i.e. **independent and identically distributed**), therefore implying that past prices cannot be used to predict future ones. A *classical random walk* models a path consisting of a succession of random steps, all independent among each other. It is often compared to a “drunkyard walk”.
For example, considering a coin toss, the position S_n after n steps can be defined as:

$$S_n = \sum_{i=1}^{n} X_i \tag{4}$$

where the X_i are independent random variables taking values $+1$ or -1 with equal probability based on the outcome of each toss.
However, empirical evidence strongly suggests that markets are not exactly random. In fact, they tend to exhibit trends, bubbles and (unfortunately) crashes, driven by the correlated behavior of participants. This behaviour is often described as “**herding**”, namely characterized by elements following mass trends generated by other elements. A classical random walk, modeling a single particle’s stochastic path, struggles to capture these complex, non-local correlations.
Quantum random walks (QRW) introduce a more powerful and efficient mechanism. Imagine a classical random walk as a person flipping a coin at every road intersection to decide whether to go left or right. A quantum random walk could be imaged as that person becoming a wave which can explore all possible paths simultaneously through superposition.
The state of a discrete time quantum walk on a line is defined by two quantum systems: a “walker” space and a “coin” space. The evolution is governed by a **coin operator** that creates a superposition of directions, followed by a conditional **shift operator** S which moves the walker:

$$|\psi_{t+1}\rangle = S(C \otimes I)|\psi_t\rangle \tag{5}$$

where C is the coin operator, I represents the *identity operator* and S shifts the walker’s position based on the coin state. This simple mechanism generates a probability distribution that spreads *quadratically faster* over the graph compared to the classical model.
This property is incredibly powerful for financial applications. The search speed of a quantum walk makes it ideal for analyzing vast and intricate networks, such as multiple interconnected assets or a decision tree of possible trades, in order to identify optimal *arbitrage opportunities* or *systemically important nodes* whose failure could trigger significant losses. Furthermore, the interference between different paths in a quantum walk allows it to naturally model the herding behavior and correlated decision-making which drive markets, helping economists and analysts achieve precise conclusions.

1.3. The investment landscape: betting on quantum computing’s future

The significant potential of these quantum tools has been surely noted by governments and general investors, leading to a rapidly growing market. In 2024, the quantum computing market share was divided like this across geographical regions:

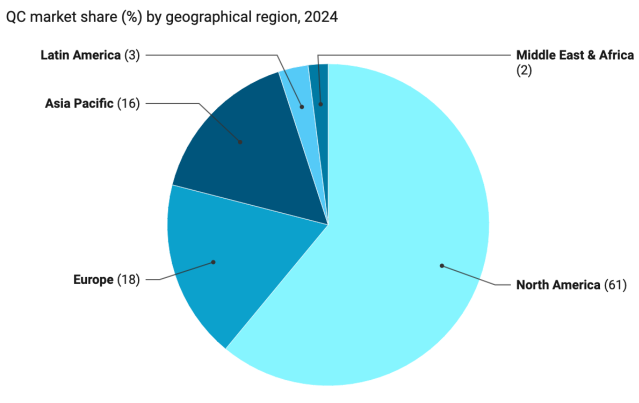

Figure 2: Source of data: Precedence Research, Quantum Computing Market Size, Share, and Trends 2025 to 2034

We can observe a quite clear dominion by the USA, however also Europe and Asia's most developed countries are steadily increasing their investments in the field.
Also, always according to Precedence Research, the global quantum computing market is projected to grow from $1.44 billion in 2025 to over $16 billion by 2034, with an impressive **CAGR** (i.e. **Compound Annual Growth Rate**) of 30.68%.

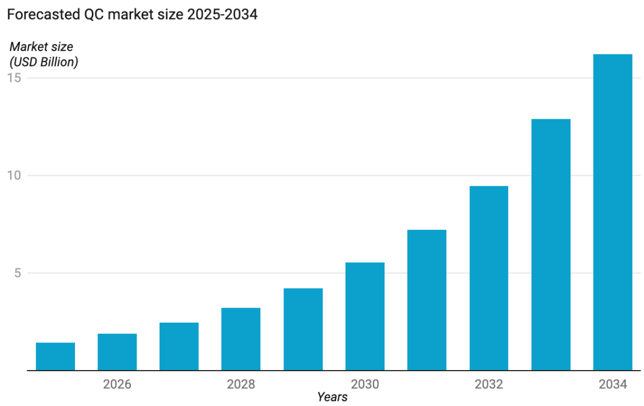

Figure 3: Source of data: Precedence Research, Quantum Computing Market Size, Share, and Trends 2025 to 2034

This is not just a tech bubble driven by collective hype: it is a pure strategic bet on the future of computation. Major banks and hedge funds are already running experiments on today's early-stage quantum computers, testing these quantum-based algorithms for tasks such as *portfolio optimization* and *derivative pricing*. Of course, they strongly hope to find the key to be early-birds in the optimal adoption of these instruments, in order to build a significant competitive advantage.
The next era is getting closer.

References

[1] General Source. Quantum financing system: A survey on quantum algorithms, potential scenarios and open research issues. *Journal of Industrial Information Integration*, 41:100663, 2024. URL: `https://doi.org/10.1016/j.jii.2024.100663`.