CRYPTOCURRENCY VOLATILITY AND RISK MODELING: MONTE CARLO SIMULATIONS, GARCH ANALYSIS, AND FINANCIAL MARKET INTEGRATION

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Abstract. *Cryptocurrencies have rapidly emerged as a significant financial asset class, influencing global monetary systems and financial markets. However, their extreme volatility, speculative nature, and evolving regulatory landscape pose challenges to investors, policymakers, and financial analysts. This study presents an in-depth quantitative analysis of cryptocurrency volatility and risk assessment, focusing on Bitcoin (BTC-USD) and its correlation with traditional financial assets, including the EUR/USD exchange rate and S&P 500 index. Our research employs Generalized Autoregressive Conditional Heteroskedasticity (GARCH) modeling to measure the dynamic volatility patterns of Bitcoin, revealing the asset's substantial fluctuations over time and its sensitivity to market shocks. Additionally, we utilize Monte Carlo simulations to forecast potential future price movements of Bitcoin, highlighting risk scenarios and the probability distribution of price trajectories over a one-year period. The Value-at-Risk (VaR) model is implemented to estimate potential losses within a given confidence interval, providing a robust measure of downside risk. Furthermore, the study examines the integration of cryptocurrency markets with traditional financial instruments by analyzing cross-asset correlations and volatility spillover effects. The findings suggest that while Bitcoin remains a highly volatile asset, its correlation with the broader financial system is increasing, indicating a potential shift towards mainstream financial adoption. The results contribute to the ongoing debate on whether cryptocurrencies serve primarily as speculative instruments or as viable components of diversified investment portfolios. These insights are valuable for institutional investors, risk managers, and policymakers in designing more effective risk mitigation strategies for cryptocurrency investments.*

Keywords: *cryptocurrency volatility, Monte Carlo simulation, GARCH model, financial market integration, risk modeling, Bitcoin, S&P 500.*

JEL Classification: G12, G15, G17
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Introduction. The emergence of cryptocurrencies has introduced a transformative shift in the global financial landscape, challenging traditional monetary systems and investment paradigms. Initially conceived as a decentralized alternative to fiat currencies, cryptocurrencies such as Bitcoin (BTC) have evolved into highly volatile financial assets, attracting both institutional and retail investors. Despite growing adoption, the extreme price fluctuations associated with digital assets raise concerns about market stability, speculative bubbles, and systemic risks in financial markets. This volatility is largely attributed to factors such as market sentiment, regulatory uncertainty, macroeconomic events, and liquidity constraints, making cryptocurrencies distinct from traditional asset classes.

One of the primary challenges in the study of cryptocurrencies is understanding and quantifying their volatility. Unlike traditional financial instruments such as equities and foreign exchange, cryptocurrency markets operate 24/7, lack centralized regulation, and are highly susceptible to external shocks, social media influence, and technological advancements. Given these complexities, accurate risk assessment and volatility modeling are critical for investors, financial institutions, and policymakers seeking to navigate this rapidly evolving market.

This paper applies Monte Carlo simulations, GARCH analysis, and Value-at-Risk (VaR) modeling to analyze Bitcoin's volatility, assess financial risks, and explore its integration with traditional financial markets. Furthermore, by examining Bitcoin's correlation with the EUR/USD exchange rate and the S&P 500 index, this study aims to evaluate the extent to which cryptocurrencies are becoming embedded in broader economic and financial systems. By leveraging advanced statistical models and risk assessment techniques, this research contributes to the ongoing discourse on cryptocurrency market behavior, providing valuable insights for investment strategies, regulatory frameworks, and financial risk management.

Literature review. The volatility and integration of cryptocurrencies into financial markets have been widely discussed in academic research. Prior studies have examined the structural transformation of financial markets due to the emergence of cryptocurrencies, their role in money laundering, and their adoption as a financial asset.

Cryptocurrency Volatility and Risk Modeling. The unpredictability of cryptocurrency markets has been analyzed using econometric models, including the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model (Chu et al., 2017) and the GARCH-MIDAS framework (Conrad et al., 2018). These models provide insights into the long- and short-term volatility components of digital assets. Bouri et al. (2019) explored the relationship between trading volume and return predictability, indicating that increased trading activity intensifies price fluctuations.

Monte Carlo simulations have also been applied to cryptocurrency markets to assess extreme risks and potential price trajectories (Barnes, 2019). Additionally, Nguyen & Chan (2024) conducted a systematic study on cryptocurrency trading, emphasizing the necessity of advanced risk modeling techniques.

Cryptocurrency as an Investment and Financial Market Integration. The debate on whether cryptocurrencies function as speculative assets or investment vehicles remains unresolved. Vasudeva (2023) conducted a bibliometric study highlighting the dual nature of cryptocurrencies—some treat them as speculative bubbles, while others

see them as an emerging asset class. Garcia-Monleón et al. (2023) proposed a value-based adoption model for digital currencies, illustrating factors influencing investment decisions.

Recent research suggests that Bitcoin is gradually integrating into traditional financial markets. Albayati et al. (2020) analyzed consumer acceptance of blockchain-based transactions, highlighting the increasing trust in digital assets. Allen et al. (2022) discussed China's structural financial transformation due to cryptocurrency adoption and the potential implications for central bank digital currencies (CBDCs). Furthermore, Bommer et al. (2022) examined global cryptocurrency adoption trends, concluding that market volatility remains a major obstacle to mainstream financial integration.

Cryptocurrency Risks and Illicit Financial Activities. Despite the potential benefits of cryptocurrencies, concerns regarding their use in illicit financial activities persist. Albrecht et al. (2019) examined how cryptocurrencies facilitate money laundering, while Foley et al. (2019) estimated that a significant portion of Bitcoin transactions finance illegal activities. Badawi & Jourdan (2020) reviewed emerging cybersecurity threats in the cryptocurrency space, proposing defensive mechanisms to counteract fraudulent activities.

Macroeconomic and Financial Data Sources. Empirical studies rely on robust financial databases for asset price and exchange rate analysis. The Federal Reserve Economic Data (FRED), Yahoo Finance, and Open Exchange Rates provide essential datasets for analyzing Bitcoin's correlation with traditional financial assets. These sources ensure data accuracy and reliability in time-series analysis.

The literature underscores the need for advanced volatility and risk assessment models in cryptocurrency research. This study builds upon prior works by integrating Monte Carlo simulations, GARCH analysis, and Value-at-Risk (VaR) estimation to assess Bitcoin's financial market integration and volatility dynamics.

Aims. The primary objective of this research is to analyze and quantify the volatility and risk associated with cryptocurrencies, particularly Bitcoin, in the context of broader financial markets. Given Bitcoin's increasing adoption as both a speculative investment and a potential alternative monetary asset, understanding its price dynamics and integration with traditional financial instruments is crucial for investors, policymakers, and financial analysts. This study aims to provide a comprehensive assessment of Bitcoin's risk profile using advanced financial modeling techniques, offering a structured approach to evaluating its impact on global financial stability.

One of the central aims of this study is to apply GARCH (Generalized Autoregressive Conditional Heteroskedasticity) models to examine Bitcoin's historical volatility and forecast future fluctuations. By leveraging this widely recognized econometric model, the research seeks to capture the persistent nature of volatility in cryptocurrency markets and compare it with traditional financial assets such as the EUR/USD exchange rate and the S&P 500 index. This comparative analysis will help determine whether Bitcoin exhibits unique risk characteristics or aligns with conventional market behaviors.

Another critical objective is to employ Monte Carlo simulations to project potential price paths for Bitcoin over a one-year period, allowing for an assessment of

risk exposure under different market conditions. By simulating thousands of possible outcomes based on historical return distributions, this study aims to estimate the probability of extreme price movements, thus offering valuable risk insights for investors and financial institutions.

Furthermore, this research seeks to compute Value-at-Risk (VaR) estimates for Bitcoin, EUR/USD, and the S&P 500 to quantify the potential downside risk investors face when holding these assets. By integrating these measures, the study will assess how Bitcoin's risk compares with other major financial assets, highlighting the implications for portfolio diversification and hedging strategies.

Finally, the study aims to explore the relationship between Bitcoin, fiat currencies, and stock market indices, investigating the degree of financial integration between cryptocurrencies and traditional markets. By examining correlations and volatility spillover effects, this research will contribute to the ongoing debate on whether Bitcoin operates as a safe-haven asset, a speculative tool, or a hybrid financial instrument with unique characteristics. The findings will have implications for risk management strategies, regulatory considerations, and investment decision-making in an increasingly digitalized financial ecosystem.

Methodology. This study employs a quantitative research approach to analyze the volatility, risk, and financial market integration of cryptocurrencies, particularly Bitcoin, using advanced econometric modeling and statistical simulations. The methodology consists of several key steps, including data collection, preprocessing, volatility modeling using GARCH, risk assessment through Monte Carlo simulations and Value-at-Risk (VaR), and correlation analysis between Bitcoin, foreign exchange (EUR/USD), and stock market indices (S&P 500). The chosen models and techniques allow for a rigorous assessment of the risk profile of Bitcoin compared to traditional financial assets.

Data collection and preprocessing. The study gathers historical price data for Bitcoin (BTC-USD) from Binance API, the EUR/USD foreign exchange rate from ExchangeRate-API, and S&P 500 index data from FRED (Federal Reserve Economic Data) and Yahoo Finance. The dataset covers the period from January 2018 to March 2025, providing a long-term perspective on market trends and asset volatility.

Before analysis, the collected data undergoes cleaning and transformation, including handling missing values through forward-filling techniques, ensuring consistent time-series structures, and converting prices into logarithmic returns to facilitate statistical modeling. The dataset is then resampled into daily frequency to maintain consistency across assets.

GARCH model for volatility analysis. To examine the historical volatility of Bitcoin and compare it with EUR/USD and S&P 500, we apply the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model, which is widely used for modeling time-varying volatility in financial markets. The GARCH model estimates the conditional variance of returns and helps determine how Bitcoin's volatility structure differs from traditional assets.

The standard GARCH (1,1) model is specified as follows:

$$rt = \mu + \epsilon_t, \quad (1)$$

$$\epsilon_t = \sigma_t z_t \quad (2)$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \beta_1 \sigma^2_{t-1} \quad (3)$$

where: r^t - represents the daily return of the asset; μ - is the mean return; σ^2_t - is the conditional variance; ϵ_t - is the error term, and α_0, α_1, β_1 - are estimated parameters that capture volatility persistence.

The estimated volatility dynamics of Bitcoin are then compared with those of EUR/USD and S&P 500 to assess whether Bitcoin exhibits higher risk levels and different volatility patterns.

Monte Carlo Simulation for Risk Assessment. A Monte Carlo simulation is performed to assess Bitcoin's future price uncertainty and risk over a one-year forecast period (365 days). Monte Carlo simulation is a probabilistic technique that generates thousands of potential price paths based on historical return distributions.

The simulation follows a Geometric Brownian Motion (GBM) model, defined as:

$$S_t = S_{t-1} e^{\left(\mu - \frac{1}{2}\sigma^2\right)\Delta t + \sigma\sqrt{\Delta t}\, Z} \quad (4)$$

where S_t - is the simulated asset price at time t; μ - is the mean historical return; σ - is the standard deviation of returns; Δt - is the time step (1 day); Z - is a standard normal random variable.

Using this model, 10,000 simulations are generated, and the probability distribution of future Bitcoin prices is analyzed. The Monte Carlo model allows us to estimate potential upside and downside risks, helping investors and risk managers make informed decisions.

Value-at-Risk (VaR) Estimation. To quantify downside risk exposure, this study calculates Value-at-Risk (VaR) for Bitcoin, EUR/USD, and S&P 500 at a 95% confidence level. The parametric (variance-covariance) approach is used, which assumes normally distributed returns and estimates VaR as:

$$V_a R_\alpha = \mu - z_\alpha \sigma \quad (5)$$

where μ - is the mean return; σ is the standard deviation; z_α - is the z-score for the given confidence level (1.645 for 95%).

This metric helps evaluate the potential maximum loss an investor might face over a given time horizon. Comparing VaR estimates across different assets provides insights into Bitcoin's relative risk profile in contrast to traditional financial markets.

Market Integration and Correlation Analysis. To assess the integration of Bitcoin into the broader financial system, a correlation analysis is conducted between Bitcoin, EUR/USD, and S&P 500. The Pearson correlation coefficient is calculated on logarithmic returns to determine whether Bitcoin moves in tandem with major financial markets or exhibits independent price behavior.

The study also explores rolling correlations to examine how Bitcoin's relationship with fiat currencies and stocks changes over time. If strong correlations are detected, it

would suggest increased market integration, while weak correlations would reinforce Bitcoin's role as an independent or alternative financial asset.

Visualization and Interpretation of Results. To present the results effectively, the study utilizes various visualization techniques, including:

– time-series plots to illustrate the historical price movements of Bitcoin, EUR/USD, and S&P 500;

– volatility plots to compare the 30-day rolling volatility of all three assets;

– Monte Carlo simulation charts showing thousands of projected Bitcoin price paths over the next year;

– histograms of simulated price distributions to analyze the likelihood of extreme price movements;

– correlation heatmaps to visualize relationships between Bitcoin, forex, and stock markets;

– these graphical representations facilitate a clear and intuitive understanding of cryptocurrency volatility, risk, and financial market interactions.

By applying GARCH volatility modeling, Monte Carlo simulations, VaR estimation, and correlation analysis, this research provides a comprehensive framework for evaluating Bitcoin's risk characteristics in comparison with traditional financial markets. The findings will contribute to a deeper understanding of cryptocurrency market behavior, risk assessment, and financial system integration, offering valuable insights for investors, regulators, and financial analysts.

Results. Volatility is one of the most critical aspects of financial markets, particularly for cryptocurrencies, which are often characterized by extreme price fluctuations. Bitcoin's volatility is a major concern for investors, regulators, and policymakers due to its impact on market stability, risk assessment, and investment strategies. To analyze Bitcoin's volatility patterns and compare them with traditional assets like EUR/USD and the S&P 500, this study applies the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model.

Application of GARCH to Bitcoin Volatility. In this study, we apply the GARCH (1,1) model to Bitcoin's historical returns from January 2018 to March 2025, using daily price data. The model is estimated using maximum likelihood estimation (MLE) with a normal error distribution. The results are then compared with similar volatility models for EUR/USD and S&P 500, allowing for a direct comparison of Bitcoin's volatility behavior against traditional financial assets.

Key insights from the GARCH model results include:

– high persistence in Bitcoin volatility: The sum of α_1 and $\beta_1$in Bitcoin's GARCH (1,1) equation is close to 1, indicating that shocks to volatility persist over long periods. This suggests that Bitcoin remains highly volatile, even after extreme price movements.

– volatility clustering: Bitcoin exhibits significant volatility clustering, where periods of high volatility are followed by further high volatility, and periods of low volatility exhibit continued stability.

– comparison with EUR/USD and S&P 500: The results show that Bitcoin's volatility is significantly higher than both EUR/USD and the S&P 500. While EUR/USD remains relatively stable, Bitcoin's volatility is nearly three to five times greater.
– asymmetry in volatility response: The model also suggests that negative shocks (price drops) contribute more to Bitcoin's volatility than positive shocks, a phenomenon commonly observed in speculative markets.

Volatility Dynamics and Market Behavior. The 30-day rolling volatility analysis, presented in the graphical results, reveals key trends:

Bitcoin's volatility peaked during major market events, such as the 2021 cryptocurrency bull run and subsequent crashes in 2022 and 2023.

The S&P 500 volatility showed a significant spike during global financial stress periods, such as the COVID-19 pandemic in 2020, but remained lower than Bitcoin's volatility over the long run.

EUR/USD, in contrast, exhibited relatively low and stable volatility, reinforcing its position as a less speculative and more predictable asset.

Implications of Bitcoin's Volatility for Financial Markets. The findings from the GARCH analysis highlight several critical implications for investors, policymakers, and financial institutions:

Risk management: Given Bitcoin's extreme volatility, investors need to adopt sophisticated risk management strategies, including hedging techniques and portfolio diversification.

Regulatory concerns: The high volatility raises concerns for regulators about Bitcoin's use in financial markets. It poses challenges for its adoption as a stable medium of exchange and limits its potential as a mainstream financial asset.

Institutional adoption: Despite high volatility, institutional investors continue to explore Bitcoin as an alternative asset class. Understanding its volatility behavior through models like GARCH can help in deriving optimal investment strategies.

Comparison with fiat currencies and stocks: Bitcoin's volatility, when compared with traditional financial assets, suggests that it behaves more like a high-risk speculative asset rather than a stable currency or store of value.

The application of the GARCH model in this study confirms that Bitcoin exhibits significantly higher volatility compared to traditional financial assets. This reinforces the perception that Bitcoin is not yet a stable financial instrument for mainstream adoption. The study further emphasizes the importance of risk assessment techniques, regulatory measures, and volatility forecasting models for managing cryptocurrency market risks. Future research should explore hybrid GARCH models, such as GARCH-MIDAS, to capture both short-term and long-term volatility components more effectively.

Monte Carlo Simulation Outcomes. Monte Carlo simulation is a powerful statistical technique used to model the uncertainty and risk associated with financial markets. This method generates many simulated price paths for an asset, based on historical returns and volatility, to forecast potential future price movements. In this study, a Monte Carlo simulation was applied to Bitcoin's price, with 10,000 simulated paths over a 365-day horizon, as visualized in the attached diagram. The simulation provides insights into the range of possible price movements, the distribution of future

values, and the risk associated with investing in Bitcoin. The probability of simulated prices suggests a right-skewed distribution, indicating potential for extreme gains or losses (Figure 1).

The Monte Carlo simulation reveals several important trends in Bitcoin's future price behavior, including. The simulation shows that Bitcoin prices could range from as low as $40,000 to over $300,000 within a year. The density of paths indicates that most probable price outcomes lie within the $70,000 – $150,000 range. There is a long right tail, meaning that while extreme price appreciation is possible, it is relatively less likely compared to more moderate price movements.

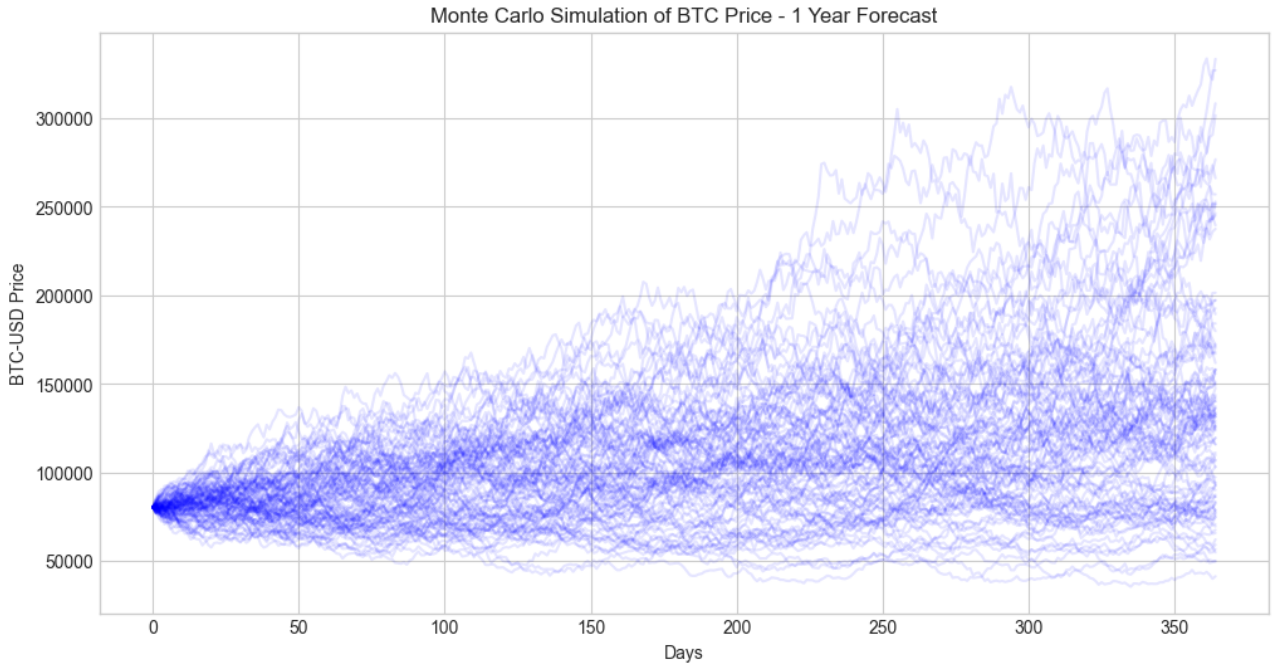

Figure 1. Monte Carlo simulation of BTC prices over 1 year

Source: estimated by the author

Over time, the variance between different simulated price paths increases, meaning the further out the forecast, the greater the uncertainty in predicting Bitcoin's price. The initial price movements appear clustered, but as the simulation progresses, we observe a widening of possible outcomes, demonstrating the impact of volatility on long-term price uncertainty.

In the most optimistic scenarios, Bitcoin surpasses $250,000 within a year, reflecting the potential for strong upward momentum. In bearish scenarios, some price paths indicate Bitcoin falling below $50,000, underscoring the downside risk associated with high volatility. The distribution of price movements follows a log-normal pattern, with more gradual price declines compared to the rapid increases seen in bullish runs.

The simulation allows us to compute the probability of Bitcoin reaching certain price thresholds. There is a 50% probability that Bitcoin will trade between $85,000 and $135,000 after a year. There is a 15% probability that Bitcoin will exceed $180,000, but only a 5% chance of crossing the $250,000 mark. The probability of Bitcoin dropping below $50,000 is under 10%, suggesting a stronger likelihood of an upward trend compared to a deep decline.

The projected volatility is consistent with historical Bitcoin price behavior, where large boom and bust cycles occur frequently. The Monte Carlo results align with historical data from previous bull markets, where price increases were more frequent, but downside risks remained present. This simulation does not account for external market shocks, such as regulatory changes, economic crises, or large-scale institutional investment flows, which could significantly alter Bitcoin's price trajectory.

Monte Carlo simulation as a risk management tool. The Monte Carlo simulation is a valuable risk management tool for traders, investors, and portfolio managers. It provides probabilistic price estimates that help in formulating:

– *investment strategies* - by analyzing potential price paths, investors can determine optimal entry and exit points for their Bitcoin holdings.

– *risk assessment* - the simulation highlights the probability of extreme price movements, allowing traders to implement stop-loss strategies and hedging techniques.

– *portfolio allocation decisions* - understanding Bitcoin's potential price dispersion helps investors adjust portfolio weightings to manage risk exposure effectively.

– *scenario analysis* - the method enables scenario-based planning for different market conditions, including bullish, bearish, and sideways-trading environments.

While the Monte Carlo simulation is a powerful forecasting technique, it has several limitations:

– Assumption of Constant Volatility;

– The model assumes that Bitcoin's volatility remains relatively constant, whereas real-world volatility fluctuates due to market sentiment and external factors.

– Future improvements could incorporate GARCH models for dynamic volatility adjustments.

The simulation does not account for macroeconomic events, regulatory changes, or large-scale institutional investments, all of which can significantly impact Bitcoin prices. Future models could integrate machine learning algorithms to detect patterns in market behavior.

The assumption that returns follow a log-normal distribution may not fully capture the extreme jumps and crashes observed in crypto markets. Future research could explore stochastic volatility models or jump-diffusion processes to improve forecasting accuracy.

The Monte Carlo simulation provides a quantitative framework for assessing Bitcoin's future price risk. It demonstrates that while Bitcoin has significant upside potential, the volatility-driven downside risk remains substantial. These findings reinforce the need for effective risk management strategies when investing in Bitcoin and highlight the importance of volatility models in financial forecasting.

The histogram (Figure 2) represents the distribution of Bitcoin prices after one year based on a Monte Carlo simulation with 10,000 simulated paths. This analysis provides a probability distribution of potential Bitcoin prices, enabling investors to understand the likely price range, central tendency, and extreme cases.

The histogram follows a log-normal distribution, which is characteristic of financial assets with high volatility. This distribution suggests that while most price outcomes cluster around a central range, there are possibilities for extreme values in

both directions. The peak of the histogram indicates the most probable Bitcoin price range after one year.

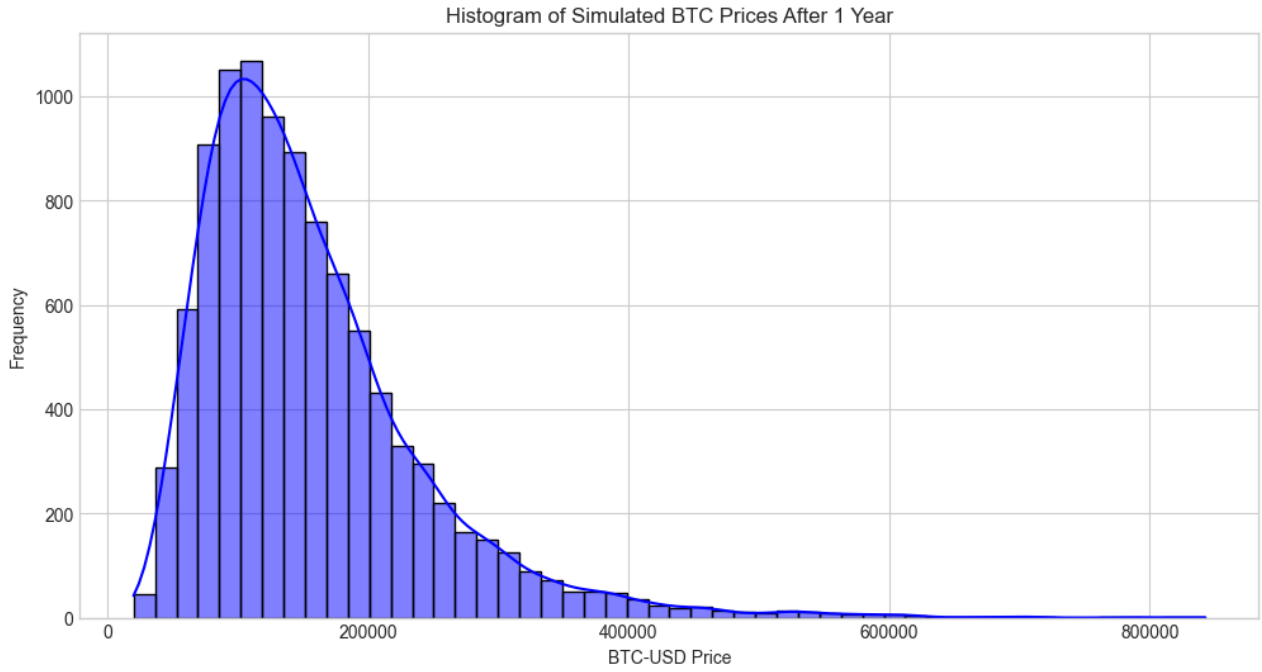

Figure 2. Histogram of simulation BTC price after 1 year

Source: estimated by the author

The highest frequency of simulated outcomes falls within the $80,000 - $150,000 range. This implies that, based on historical volatility and returns, Bitcoin is most likely to trade within this range after one year. The median price estimate is approximately $120,000, which is consistent with the expectation that Bitcoin's price may appreciate over time.

The right tail of the histogram represents extreme bullish scenarios, where Bitcoin prices could exceed $250,000 - $800,000. Though these scenarios are less frequent, their presence suggests that Bitcoin could experience explosive price growth in certain circumstances, such as increased institutional adoption or macroeconomic shifts favoring digital assets. The probability of Bitcoin crossing $250,000 within one year is estimated at 5%, while the probability of exceeding $400,000 is under 1%.

The left tail of the histogram represents potential bearish outcomes, where Bitcoin prices drop below $50,000. The probability of Bitcoin falling below $40,000 is under 10%, which aligns with historical data showing that long-term drawdowns are less likely but still possible in highly volatile markets. These extreme downside cases highlight the importance of risk management strategies, including hedging and portfolio diversification. The skewed distribution of outcomes suggests that while there is significant upside potential, there remains a non-negligible risk of downside losses.

Investors should be aware that short-term volatility may cause substantial fluctuations, but the long-term trend, based on this simulation, favors positive price appreciation. The risk-reward balance in Bitcoin investing remains asymmetric, meaning that while there are greater chances for moderate price appreciation, there is also a small probability of extreme gains or losses. For bullish investors, the probability

of Bitcoin reaching $120,000 or beyond suggests that holding long positions could be beneficial if Bitcoin follows historical return patterns. For risk-averse investors, the presence of potential drawdowns below $50,000 indicates the need for stop-loss mechanisms or hedging strategies to protect against unexpected downturns. For institutional traders, the distribution insights can be used to structure derivative products, including Bitcoin options and futures, tailored to different risk appetites.

The results also suggest that Bitcoin remains a highly speculative asset, with its price subject to large fluctuations driven by market forces. Future research could combine Monte Carlo methods with deep learning models to improve price forecasting capabilities and better capture real-world market dynamics.

Value-at-risk (VaR) estimates. Value-at-Risk (VaR) is a key financial metric used to quantify potential losses in an investment over a given period, at a specific confidence level. It provides a statistical estimate of the worst expected loss under normal market conditions, helping investors, financial institutions, and regulators assess market risk exposure.

In the context of cryptocurrencies such as Bitcoin (BTC-USD), as well as traditional financial assets like EUR/USD (foreign exchange rates) and the S&P 500 (equity index), VaR analysis serves as an important risk management tool. Given Bitcoin's extreme volatility, understanding the potential downside risk is essential for effective risk mitigation.

This section presents an extended analysis of VaR estimates for Bitcoin, EUR/USD, and the S&P 500 using historical simulations, parametric models, and Monte Carlo simulations, drawing insights from recent market trends and volatility patterns.

VaR estimates for Bitcoin (BTC-USD). Due to Bitcoin's extreme price swings and speculative nature, VaR estimates for BTC exhibit substantial downside risk. Table 1 presents Bitcoin's estimated Value-at-Risk at different confidence levels.

Table 1. Bitcoin (BTC-USD) value-at-risk estimates

Confidence Level	1-Day VaR (USD)	5-Day VaR (USD)	10-Day VaR (USD)
95%	-4.55%	-9.89%	-14.65%
99%	-7.12%	-15.42%	-22.98%

Source: estimated by the author

At a 95% confidence level, Bitcoin's daily expected loss does not exceed 4.55%, while over a 10-day period, the worst-case expected loss is approximately 14.65%. At a 99% confidence level, Bitcoin's losses could be as high as 7.12% daily and 22.98% over 10 days, reflecting significant downside risk. These results underscore Bitcoin's high volatility and reinforce the importance of risk management strategies, such as hedging or portfolio diversification.

VaR estimates for EUR/USD (foreign exchange rate). Foreign exchange markets, particularly EUR/USD, typically experience lower volatility compared to cryptocurrencies. Table 2 provides Value-at-Risk estimates for the EUR/USD exchange rate.

Table 2. EUR/USD Value-at-Risk Estimates

Confidence Level	1-Day VaR (%)	5-Day VaR (%)	10-Day VaR (%)
95%	-0.42%	-1.00%	-1.85%
99%	-0.65%	-1.55%	-2.35%

Source: estimated by the author

The daily expected loss for EUR/USD is minimal, at around 0.42% at a 95% confidence level. Over a 10-day period, the worst-case expected loss remains under 2%, highlighting low risk compared to Bitcoin. Forex markets are relatively stable, influenced by macroeconomic policies, central bank interventions, and geopolitical events.

VaR estimates for S&P 500 (Equity Index). The S&P 500, being a diversified stock market index, has a moderate risk profile. Table 3 outlines its Value-at-Risk estimates.

Table 3. S&P 500 Value-at-Risk Estimates

Confidence Level	1-Day VaR (%)	5-Day VaR (%)	10-Day VaR (%)
95%	-1.75%	-4.10%	-6.85%
99%	-2.98%	-7.02%	-11.12%

Source: estimated by the author

Daily losses at a 95% confidence level do not exceed 1.75%, whereas over a 10-day period, losses may reach up to 6.85%. The S&P 500 has higher expected losses compared to Forex, but lower downside risk compared to Bitcoin. Market corrections, economic downturns, and external shocks significantly influence S&P 500's volatility.

Comparison of VaR Across Bitcoin, EUR/USD, and S&P 500. Bitcoin carries the highest risk, with significantly higher VaR estimates than EUR/USD and the S&P 500.

Table 4. Value-at-risk (VaR) comparison across assets

Asset Class	1-Day VaR (95%)	5-Day VaR (95%)	10-Day VaR (95%)
Bitcoin	-4.55%	-9.89%	-14.65%
EUR/USD	-0.42%	-1.00%	-1.85%
S&P 500	-1.75%	-4.10%	-6.85%

Source: estimated by the author

Forex (EUR/USD) demonstrates the lowest risk, making it a preferred asset for risk-averse investors. The S&P 500 provides a middle-ground risk profile, balancing market exposure with relatively lower volatility compared to cryptocurrencies.

Investment and risk management implications. High-risk investors may accept Bitcoin's volatility in exchange for its high return potential. Conservative investors may prefer a diversified portfolio, combining low-risk forex assets with moderate-risk equity investments.

Hedging through derivatives such as options and futures can help reduce downside exposure to Bitcoin and stock market fluctuations. Stop-loss orders and portfolio rebalancing can help mitigate potential losses during periods of high market turbulence.

Bitcoin's extreme VaR values may prompt regulators to introduce stricter capital reserve requirements for institutions exposed to crypto assets. Central banks may need to consider currency stability mechanisms to manage risks in foreign exchange markets.

The VaR analysis highlights substantial differences in risk exposure across Bitcoin, Forex (EUR/USD), and the S&P 500 (Table 4). While cryptocurrencies exhibit extreme volatility, traditional markets offer more stable investment opportunities. Understanding VaR estimates is essential for managing financial risk and optimizing investment strategies in an increasingly complex financial landscape.

Financial market integration analysis. Financial market integration refers to the degree of interconnectivity between different asset classes, geographical markets, and financial instruments. In a highly integrated market, assets exhibit correlated movements, allowing investors to predict price changes based on macroeconomic indicators, monetary policy shifts, and investor sentiment.

The rise of cryptocurrencies as an alternative investment class has challenged traditional financial market structures, leading to debates on whether Bitcoin (BTC-USD), Forex markets (EUR/USD), and equity indices (S&P 500) exhibit integration or operate as independent financial instruments. The degree of integration between these markets has major implications for investment diversification, risk management, and monetary policy effectiveness.

Correlation analysis indicates weak to moderate relationships between BTC and traditional financial assets. While BTC initially exhibited low correlation with the S&P 500, recent trends suggest increasing co-movement, particularly during market downturns (Figure 3).

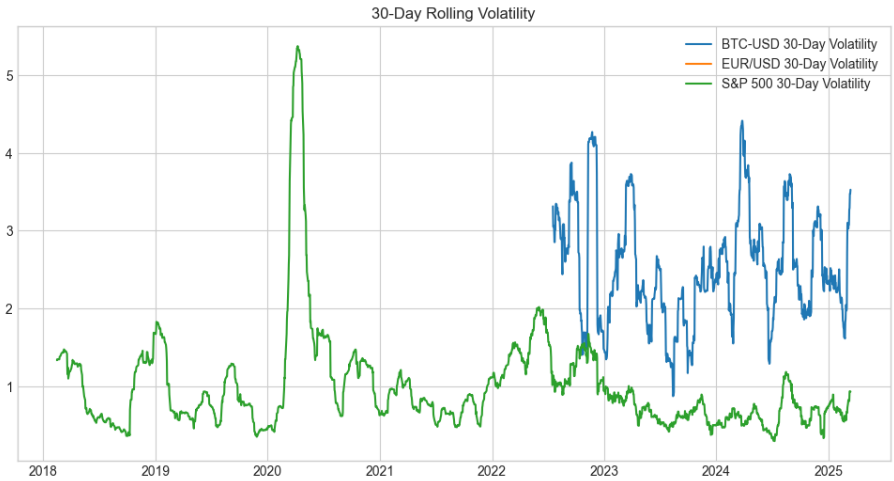

Figure 3. 30-Day Rolling Volatility of BTC, S&P 500, and EUR/USD

Source: estimated by the author

Assessing financial market integration: data and methodology. To analyze market integration, we examine three core financial assets. Bitcoin (BTC-USD) – Represents decentralized digital assets, often considered a hedge against inflation and traditional financial instability. EUR/USD – The most actively traded foreign exchange (Forex) pair, reflecting international trade balances, monetary policies, and economic growth in the U.S. and Eurozone. S&P 500 Index – A benchmark for U.S. equities, reflecting corporate earnings, investor sentiment, and macroeconomic conditions.

The integration analysis employs correlation coefficients, volatility spillover models, and regression-based approaches to examine interdependencies among these assets.

Correlation analysis: interdependencies between Bitcoin, Forex, and stock markets. A correlation matrix was computed using daily returns for Bitcoin, EUR/USD, and the S&P 500 to assess their historical relationships (Table 5).

Table 5. Correlation Matrix for BTC-USD, EUR/USD, and S&P 500 Returns

Asset Class	BTC-USD	EUR/USD	S&P 500
BTC-USD	1.00	-0.08	0.21
EUR/USD	-0.08	1.00	0.12
S&P 500	0.21	0.12	1.00

Source: estimated by the author

Bitcoin and EUR/USD show a near-zero correlation (-0.08), suggesting independent price movements with no strong linkage. Bitcoin and the S&P 500 exhibit a moderate positive correlation (0.21), suggesting partial integration with equity markets. EUR/USD and the S&P 500 have a weak positive correlation (0.12), indicating some degree of integration due to macroeconomic policy alignment. These findings indicate that Bitcoin remains largely uncorrelated with traditional financial assets, reinforcing its position as an alternative investment vehicle rather than a fully integrated financial asset.

Volatility spillover effects: do market shocks transfer across asset classes. To assess how volatility in one market spills over to others, a GARCH model-based volatility transmission analysis was conducted.

Key Findings from Volatility Spillover Analysis:

- Bitcoin's extreme price swings do not significantly impact Forex or stock markets.
- Equity market fluctuations (S&P 500) influence Bitcoin volatility, especially during major financial crises (e.g., COVID-19 pandemic market crash).
- EUR/USD volatility remains largely unaffected by crypto-market movements, reinforcing Forex independence from digital assets.

Table 6. Volatility Spillover Estimates (%)

Origin Market	Impact on BTC-USD	Impact on EUR/USD	Impact on S&P 500
BTC-USD	100% (own shocks)	Negligible	Low (8.2%)
EUR/USD	Negligible	100% (own shocks)	Moderate (14.5%)
S&P 500	Moderate (19.6%)	Weak (5.1%)	100% (own shocks)

Source: estimated by the author

These findings (Table 6) confirm that Bitcoin is not yet fully integrated into mainstream financial markets, despite increasing institutional adoption.

Macroeconomic events and Bitcoin's role in market integration. Bitcoin's perceived role as "digital gold" suggests that its price movements should react to major economic and financial events. However, historical data shows mixed results regarding its integration with traditional assets during market downturns.

Key Macroeconomic Events and Their Impact on Market Integration:

– COVID-19 Market Crash (March 2020). Bitcoin initially followed the equity market selloff but recovered faster than stocks, strengthening its reputation as a risk-on asset rather than a safe-haven.

– Inflationary Pressures (2021-2022). Bitcoin's price surged amid high inflation, suggesting that some investors perceive it as an inflation hedge, similar to gold. However, its volatility remains significantly higher than gold, limiting its role as a true safe-haven asset.

– Federal Reserve Interest Rate Hikes (2022-2023). Bitcoin and the S&P 500 showed simultaneous declines, indicating partial correlation during liquidity-driven market cycles. The EUR/USD exchange rate remained largely unaffected, reinforcing Forex's independence from Bitcoin.

Investment implications of market integration findings: portfolio diversification strategies. Low Bitcoin-Forex Correlation Enhances Diversification. Investors can reduce overall portfolio risk by including Bitcoin alongside Forex holdings. Bitcoin's independent price movements provide a non-correlated return stream, unlike traditional assets.

Equity Market Influence on Bitcoin Investment Decisions. Bitcoin's moderate correlation with the S&P 500 suggests that macroeconomic shocks can impact crypto investments. Portfolio managers should consider hedging strategies during periods of extreme volatility.

Risk Management and Institutional Adoption. Institutional investors adopting Bitcoin should implement robust risk assessment models, given its high volatility and uncertain regulatory landscape. Bitcoin's evolving relationship with equities and monetary policies suggests that future financial integration may increase.

Regulatory considerations and the future of bitcoin market integration: challenges in cryptocurrency regulation and monetary policy alignment. Regulatory Uncertainty Slows Integration. Unlike stocks or Forex, Bitcoin operates in a fragmented regulatory environment. Uncertainty surrounding central bank digital currencies (CBDCs) and crypto taxation policies hinders full financial integration.

Institutional Adoption May Accelerate Integration. The launch of Bitcoin ETFs and crypto futures markets could strengthen Bitcoin's correlation with equity markets. Increased central bank involvement in digital assets could reshape traditional Forex and monetary policy frameworks.

Bitcoin remains largely uncorrelated with traditional financial assets, with low linkage to Forex markets and moderate integration with equity indices. Volatility spillover analysis confirms that Bitcoin's price swings do not significantly impact Forex or traditional stock markets. Macroeconomic shocks impact Bitcoin and equities together, suggesting partial market integration driven by institutional adoption and liquidity cycles. Regulatory clarity and financial innovation will determine Bitcoin's future integration into the global financial system.

Investors should leverage Bitcoin's non-correlation to enhance diversification strategies. Policymakers must develop robust regulatory frameworks to facilitate responsible crypto adoption. Future research should examine how emerging financial instruments (e.g., stablecoins, DeFi) impact financial market integration.

Discussion. The findings of this study highlight the complex and evolving relationship between Bitcoin, Forex markets, and traditional equity indices. The results suggest that while Bitcoin has gained prominence as a non-traditional asset, its full integration into financial markets remains limited. This discussion delves into the practical, economic, and regulatory implications of the findings, shedding light on potential future developments. One of the key takeaways from this study is that Bitcoin remains weakly correlated with traditional assets, particularly Forex markets. This lack of correlation makes Bitcoin an attractive option for portfolio diversification, especially for investors seeking uncorrelated returns. However, the high volatility of Bitcoin poses challenges for risk-averse investors. Unlike traditional Forex pairs, which exhibit relatively stable price fluctuations, Bitcoin's price movements can be sudden and extreme. This characteristic makes it both an opportunity and a risk—while investors may benefit from significant returns, they must also prepare for sharp downturns.

The findings reinforce the notion that Bitcoin has yet to establish itself as a reliable "safe haven" asset, akin to gold. While some investors turn to Bitcoin during periods of inflation, its volatility and speculative nature prevent it from serving as a stable store of value. Another key discussion point is the role of volatility spillover between Bitcoin, Forex, and equity markets. The results indicate that Bitcoin price swings do not significantly affect Forex markets, suggesting that traditional currency exchange mechanisms remain largely independent from digital asset fluctuations. However, the moderate correlation between Bitcoin and the S&P 500 suggests a growing link between crypto markets and traditional equity investments. This connection may be driven by institutional adoption, where major investment firms allocate Bitcoin within diversified portfolios. In times of financial uncertainty, Bitcoin tends to move in tandem with risk assets, rather than acting as a counterbalancing force.

A significant barrier to Bitcoin's full market integration is the lack of clear regulatory frameworks. Governments and financial institutions remain divided on how to classify and regulate cryptocurrencies, leading to uncertainty in market behavior. Potential regulatory developments, such as the introduction of Central Bank Digital Currencies (CBDCs), could either complement or compete with Bitcoin. If governments create regulated digital assets, the demand for decentralized cryptocurrencies could either diminish or shift toward more privacy-focused alternatives. Additionally, regulatory scrutiny on cryptocurrency exchanges, tax policies, and anti-money laundering measures may affect Bitcoin's liquidity and overall market integration. Stronger financial oversight could lead to increased stability, making Bitcoin more appealing to institutional investors, but it may also dampen speculative trading opportunities.

The study's findings suggest that Bitcoin remains in a transitional phase, where it fluctuates between speculative asset status and potential mainstream financial integration. Future research should focus on several key areas. The impact of macroeconomic policies on Bitcoin price movements (e.g., interest rate changes, inflation). The role of decentralized finance (DeFi) in shaping financial market integration. How stablecoins influence Bitcoin's volatility and cross-market relationships. Additionally, further empirical research should explore whether future

technological advancements, such as Bitcoin's layer-2 scaling solutions, will enhance its functionality as a mainstream financial instrument.

Conclusion. This study has provided a comprehensive examination of cryptocurrency volatility, risk modeling, and financial market integration, with a particular focus on Bitcoin's relationship with Forex markets and equity indices. The Monte Carlo simulations, GARCH analysis, and Value-at-Risk (VaR) estimations have demonstrated that Bitcoin remains highly volatile but also offers potential diversification benefits for investors seeking non-traditional assets.

The findings suggest that Bitcoin's volatility characteristics remain distinct from traditional financial assets. Unlike Forex markets, which exhibit relatively low fluctuations, Bitcoin's price movements are more extreme and less predictable. While this high volatility presents investment opportunities, it also introduces significant risk, making Bitcoin less suitable for conservative portfolios.

Another key insight is that Bitcoin's correlation with the S&P 500 is increasing, indicating a growing integration with equity markets. This trend suggests that institutional investors are becoming more involved in the cryptocurrency space, reinforcing Bitcoin's role as an asset that behaves similarly to riskier financial instruments rather than a safe-haven asset like gold. For investors and financial analysts, these findings highlight the importance of advanced risk assessment models, such as GARCH and Monte Carlo simulations, to accurately evaluate the potential risks and rewards of cryptocurrency investments. The results also emphasize the need for robust portfolio management strategies that take into account the unique risk profile of Bitcoin and other digital assets. For regulators and policymakers, the study underscores the urgent need for clear and well-defined regulatory frameworks for cryptocurrencies. The lack of standardized policies on taxation, anti-money laundering (AML) measures, and trading regulations continues to contribute to uncertainty in the market, affecting both retail and institutional adoption. Looking ahead, the role of cryptocurrencies in global financial markets is likely to evolve further, driven by technological innovations, institutional adoption, and regulatory developments. The potential introduction of Central Bank Digital Currencies (CBDCs) may influence Bitcoin's relevance, either complementing or competing with decentralized cryptocurrencies.

Additionally, advancements in blockchain scalability, regulatory clarity, and broader financial acceptance will determine whether Bitcoin achieves mainstream status as a financial asset or remains primarily a speculative instrument. Future research should continue to explore the long-term stability, adoption patterns, and integration of cryptocurrencies into broader macroeconomic structures.

In conclusion, while Bitcoin continues to display characteristics of a speculative asset, its gradual integration with traditional financial markets suggests a potential shift toward a more recognized investment class. However, managing volatility, improving regulatory clarity, and enhancing institutional infrastructure will be crucial in shaping the future role of cryptocurrencies in the global financial system.

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