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Efficiency and Pricing of Bitcoin Options

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ABSTRACT:

The aim of this thesis is to examine the pricing and efficiency of Bitcoin options. It reviews theories of market efficiency and considers how effectively these frameworks apply to cryptocurrency markets.

The thesis examines multiple option pricing models by comparing their performance for pricing Bitcoin options. Bitcoin's high volatility and the relatively young age of its market development highlight the need to analyze how these characteristics influence both option pricing and overall market efficiency.

In addition, the thesis examines the characteristics of Bitcoin options. The study provides guidelines for future research and market development, helping to build trust and support the integration of cryptocurrency derivatives into the broader financial system.

KEYWORDS: Bitcoin, options, volatility, market efficiency

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TIIVISTELMÄ:

Tämän opinnäytetyön tavoitteena on tarkastella Bitcoin-optioiden hinnoittelua ja markkinoiden tehokkuutta. Työssä käydään läpi markkinatehokkuuden teorioita ja arvioidaan, kuinka hyvin nämä viitekehukset soveltuvat kryptovaluuttamarkkinoihin.

Opinnäytetyössä tarkastellaan useita optioiden hinnoittelumalleja vertailemalla niiden toimivuutta Bitcoin-optioiden hinnoittelussa. Bitcoinin korkea volatilitiiteetti ja sen markkinoiden suhteellisen varhaisessa kehitysvaiheessa oleva tila korostavat tarvetta analysoida, miten nämä ominaisuudet vaikuttavat sekä optioiden hinnoitteluun että markkinoiden yleiseen tehokkuuteen.

Lisäksi työssä tarkastellaan Bitcoin-optioiden erityispiirteitä. Tutkimus tarjoaa suuntaviivoja tulevalle tutkimukselle ja markkinoiden kehittämiseksi, ja sen tavoitteena on lisätä luottamusta sekä tukea kryptovaluuttajohdannaisten integroitumista laajempaan finanssijärjestelmään.

AVAINSANAT: Bitcoin, options, volatility, market efficiency

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1 Introduction

The cryptocurrency market is significantly more volatile than traditional financial markets. This high level of risk increases the need for robust risk management strategies, for which derivatives play a crucial role. Cryptocurrency-related derivatives first entered the market in 2011, while Bitcoin options were introduced on the Deribit exchange in 2016, marking the beginning of a relatively new sector in financial markets. Initially, the user base for these instruments was limited, but as the broader crypto market has grown, investor demand for sophisticated risk management tools has increased in parallel.

The high volatility and the underdeveloped structure of the market make this topic relevant. In addition, the predicted growth of the cryptocurrency and derivatives market highlights the need for studies that further examine the pricing and efficiency of Bitcoin options. This financial instrument has experienced huge price movements in the past. In the world of cryptocurrency, major price movements occur in cycles. These cycles are described as bull and bear cycles. For example, Bitcoin's price increased from under €1,000 to nearly €17,000 during 2017. This bull run was followed by a bear market in 2018. During the bear market Bitcoin lost over 80% of its value. A similar pattern appeared between 2020 and 2022. During this period Bitcoin's value rose above €60,000. After this, the price declined below €20,000. As of November 2025, Bitcoin trades at approximately €100,000, down from its all-time high of €124,290. Bull and bear cycles show the high volatility of Bitcoin and the challenging nature of cryptocurrency markets. Conditions observed in the spot market of Bitcoin create challenges for option markets. A study by Cao and Celik (2021) highlights the problem: there is no accurate pricing model for Bitcoin options due to challenges in its markets.

As long as the efficiency and pricing of Bitcoin options remains challenging, participation in its markets will not improve significantly. The need for improved informational efficiency and the ability to process the volatility of Bitcoin is essential in the future. The role of the financial markets is to collect and distribute information, as stated in a study by Alexander et al. (2023). This study aims to contribute to this need. The importance of

Bitcoin options in the financial system is expected to grow in the future. In order to contribute to a deeper understanding of the efficiency and pricing of Bitcoin options, this study examines existing studies that explore different market efficiency frameworks and pricing models that try to capture the characteristics of Bitcoin.

1.1 Purpose of This Study

This study aims to address the challenges in efficiency and pricing of Bitcoin options. The first area of interest is volatility. The study will focus on how volatility affects the pricing of Bitcoin options. The focus will be on comparing the use of different pricing models and examining how they perform in capturing the volatility of Bitcoin. The first hypothesis is as follows:

H_1 = The volatility of Bitcoin has a significant impact on the pricing of Bitcoin options.

The second area of interest is related to market efficiency. The study will examine the market efficiency of Bitcoin options and compare it to traditional markets. By comparing the efficiency to traditional financial counterparts, the study will explore how the unique characteristics of Bitcoin affect the efficiency. The second hypothesis is as follows:

H_2 = Bitcoin options markets are less efficient than traditional options markets.

1.2 Structure of Thesis

The thesis includes seven chapters. Chapter one introduces the purpose of the study. It also presents the hypotheses and the structure of the thesis. Chapter two focuses on market efficiency. It presents two theoretical frameworks that are used to examine the efficiency of Bitcoin. Chapter three focuses on the basics of Bitcoin and options. Chapter four investigates the structure of the Bitcoin options market. Chapter five examines option pricing models. It has a particular focus on volatility. Chapter six is the analysis and

discussion, which addresses the hypotheses of the study. Chapter seven concludes the study with a conclusion.

2 Market Efficiency – Theoretical Background

This chapter will focus on market efficiency in Bitcoin markets. The chapter introduces two theoretical frameworks. The first framework is the Efficient Market Hypothesis (EMH) and the second one is the Adaptive Market Hypothesis (AMH). By combining the two theoretical frameworks, the study provides different perspectives on how efficiency is measured.

When measuring efficiency in the Bitcoin options markets, the connection between the spot and the options markets must be considered. According to the study, there are clear differences between these two markets. A study by Chen and Yang (2024) investigates this connection and finds clear differences. The study finds that the Bitcoin spot market is the primary driver of price determination. Furthermore, the spot market processes information more quickly and accurately compared to the options market. In times of high volatility and rapid price changes, the options market adapts especially slowly to the changing market dynamics.

Most studies presented in this chapter are based on the Bitcoin spot market. Inefficiencies measured on the spot market affect the options market. Therefore, understanding the behavior and structure of the spot market is crucial when evaluating the pricing accuracy and overall efficiency of Bitcoin options.

2.1 Efficient Market Hypothesis

According to the general principle, markets are considered efficient when all new information is immediately and accurately reflected in the prices of stocks, securities, or cryptocurrencies. In such a market, no participant can consistently earn excess returns by exploiting available information. The hypothesis that describes this concept is known as the Efficient Market Hypothesis (EMH), originally proposed by Fama (1970).

Fama (1970) introduced three conditions, which can be used to determine whether markets are efficient. These conditions are as follows:

- i) Trading securities involves no transaction costs
- ii) All market participants have free and equal access to all available information
- iii) Everyone interprets the available information in the same way regarding current asset value and future price distributions

According to Fama (1970), there are three forms of market efficiency. The first one is the weak form, which suggests that all historical data are already reflected in current asset prices. The second is the semi-strong form, which states that all publicly accessible information is reflected in asset prices. The third is the strong form of efficiency, which goes even further. The strong form means that asset prices reflect all information, meaning that insider information is already accounted for in the market price. The forms can be tested in different ways, including autocorrelation models, event studies or variance ratio tests.

The fulfillment of these conditions is not self-evident in modern finance. According to Degutis and Novickytė (2014), the efficient market hypothesis is nowadays seen more as a relative concept than an absolute one. EMH fails to explain several market conditions, such as market bubbles, volatility spikes and investor overreactions.

Although EMH serves as a cornerstone in financial theory, its relevance to cryptocurrency markets is limited. Crypto markets differ from traditional ones due to their relative immaturity, reduced regulation, high volatility, and lower liquidity. These features introduce frictions that can delay information processing and generate pricing anomalies, which are inconsistent with EMH.

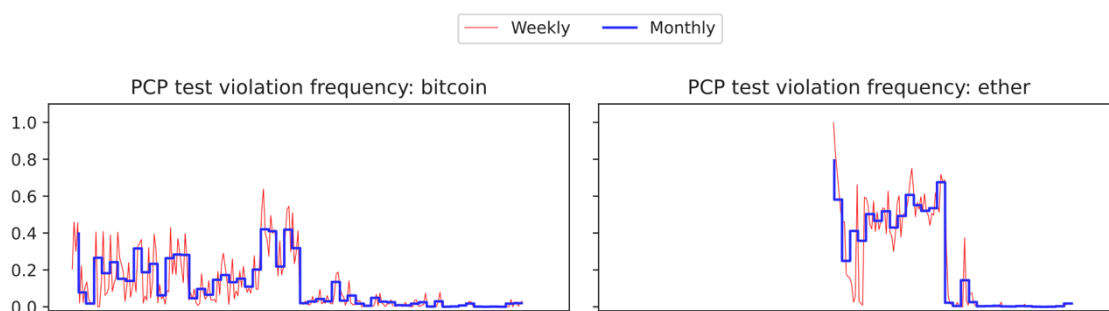


Figure 1. Weekly and monthly violation frequencies of the efficiency tests. (Alexander et al. 2024)

Recent research has examined the extent to which the EMH holds in crypto derivatives markets. A study by Alexander et al. (2024) tested put–call parity and related arbitrage strategies in Bitcoin options and futures. They found that Bitcoin’s derivatives markets are becoming more efficient over time, especially for longer-maturity options. In figure 1, the sample is from January 1, 2019, to September 30, 2023, for Bitcoin derivatives and from April 1, 2021, to September 30, 2023, for ether derivatives. From the figure, for both Bitcoin and Ethereum derivatives, violations occurred much more frequently at the beginning of the test period. Over time, the violations have almost completely disappeared, which indicates that the markets have become more efficient and that arbitrage opportunities have significantly decreased.

The study by Alexander et al. (2024) also documented persistent arbitrage opportunities that remain profitable even after accounting for transaction costs. Inefficiencies appear mostly in short-term contracts under high volume or network congestion. According to the study, the Bitcoin option market is inefficient, However, the Bitcoin options market is showing signs of maturing as noted in the study.

In addition to arbitrage opportunities, research on how Bitcoin option prices incorporate relevant information has been conducted. According to the study by Alexander et al. (2023) at-the-money (ATM) option prices are primarily driven by volatility trading, and out-of-the-money (OTM) option prices show the influence of both volatility trading and informed trading. The presence of possible informed trading suggests that some market

participants may hold a short-term informational advantage. This finding violates the principles of the EMH and indicates that the Bitcoin option market is not efficient according to this hypothesis. According to the findings mentioned, the use of EMH as a framework to evaluate efficiency in cryptocurrencies must be considered carefully.

2.2 Adaptive Market Hypotheses

Adaptive Market Hypothesis (AMH) can be described as a modern extension of the EMH. This framework was developed by Lo (2004), and it sees market efficiency as an evolving and adaptive process. The AMH combines elements used in EMH with behavioral economics. One of its key differences compared to EMH is the view of how investors act. According to the AMH, investors do not always behave rationally. Furthermore, the AMH considers market conditions to change continually. The AMH can be used as a framework to analyze the market efficiency of Bitcoin options.

In the study conducted by Lo (2004), four practical implications were identified. Identified implications can be described as below:

- i) The risk-return relationship is not stable over time
- ii) Arbitrage opportunities arise periodically
- iii) Investment strategy performance is cyclical
- iv) Adaptability and innovation are critical for survival

According to the implications made by Lo (2004), the framework of AMH may be useful for examining the market efficiency of Bitcoin options. Multiple studies (Chu et al., 2019; Karasiński, 2023; Ghazani & Jafari, 2021) support this view. According to these studies, the AMH is a useful and realistic framework to analyze this market. Findings conclude that efficiency in cryptocurrency derivatives markets, including the Bitcoin options market, is not binary or static. Efficiency seems to change over time, depending on different market conditions.

The study by Chu et al. (2019) supports the view that the efficiency of the market changes over time. They examined high-frequency data for Bitcoin and Ethereum, and found that market efficiency changes over time. The findings are consistent with AMH's assumptions. A study by Ghazani and Jafari (2021) further supports this view. Similarly, the study concludes that market efficiency of cryptocurrency derivatives is not constant. According to the studies mentioned, market efficiency is cyclic, and it moves through different periods of predictability and unpredictability.

A study by Karasiński (2023) comes to the same conclusion. The study that examined 40 different cryptocurrencies states that most coins show temporary inefficiencies at multiple points in the time period between 2013 and 2022. Inefficiencies were mostly momentary. The findings support the use of AMH. Based on Lo's (2004) implications, arbitrage conditions can arise, but the market eventually corrects itself and the inefficiencies are eliminated.

Based on the three studies mentioned in this subsection, the AMH offers a more flexible framework, compared to the EMH, to examine the efficiency of markets that have the same characteristics as the cryptocurrency derivatives market. It can provide a basis to understand efficiency as it exists in today's modern markets.

3 Fundamentals of Options and Bitcoin

This chapter introduces the basics of options and Bitcoin. Understanding both options and Bitcoin is important before moving on to Bitcoin option pricing. The basics of options are discussed briefly. Furthermore, the chapter gives insight into what Bitcoin is and how it is positioned in the market.

3.1 Overview of Options

Chisholm (2010) defines options as financial derivatives whose value is derived from the price movements of an underlying asset. Options are categorized into two groups: call options and put options. A call option allows the buyer to choose to purchase the underlying asset at a set price on the expiration date, or before. Alternatively, a put option gives the buyer the choice to sell the asset at a set price during the same period. Options give the holder the right, but not the obligation to buy or sell the underlying asset at a set price.

Options exist in different styles depending on the rules governing their exercise. American options can be exercised at any point before or at expiration. European options, on the other hand, are exercisable only at maturity. A third variant, the Bermudan option, allows exercise on specific predetermined dates. The style of the option affects its valuation and risk characteristics.

The intrinsic value of an option is how much money would be made if the option were exercised. The amount is the difference between the strike price and the current market price. It represents the immediate cash gain that would be realized if the option were exercised immediately. If the strike price of the option is equal to the market price, the option has no intrinsic value. This is called an at-the-money option. Even if an option has no intrinsic value, it may still have a market value due to its time value. Time value reflects the possibility that the intrinsic value of the option may change before it expires. The total value of an option consists of the sum of its intrinsic value and time value.

A call option has value when it is considered in-the-money. This means its strike price is below the current market price of the asset. If the strike price is above the market price, the call is considered out-of-the-money. In contrast, a put option is in-the-money when its strike price is above the market price, and out-of-the-money when the strike price is below the market price.

Options pricing is commonly modeled using the Black–Scholes framework, which assumes log-normal returns and constant volatility (Black & Scholes, 1973). The model is widely used, but it is based on assumptions that may not hold in all markets. Markets characterized by high volatility and non-normal return distributions are prone to deviations from these assumptions.

3.2 Overview of Bitcoin

Bitcoin is a digital currency that was introduced to the public in 2009, and it is currently the biggest cryptocurrency in the markets. Bitcoin operates directly between users without third parties such as banks and they enter the circulation by the process which is called mining. Bitcoin is considered an alternative investment asset that provides hedging opportunities against traditional markets and currencies. It can be a versatile tool in portfolio management due to its characteristics.

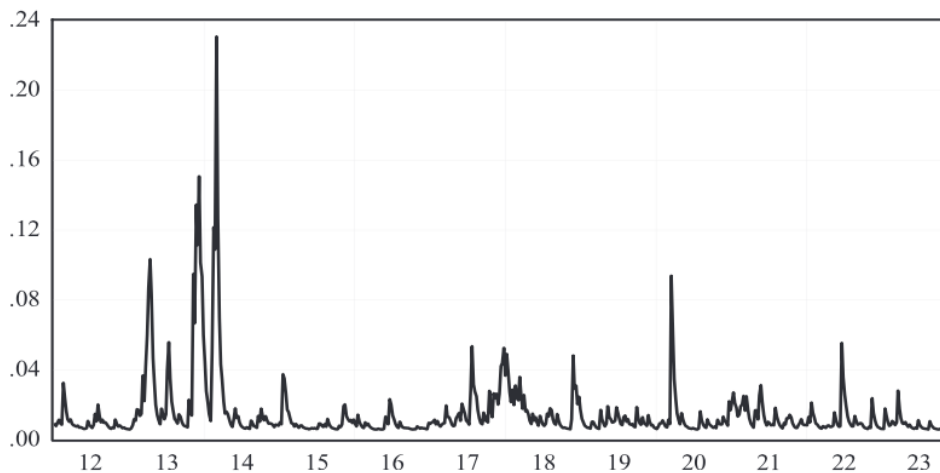


Figure 2. Representation of Bitcoin price volatility (Köse et al. 2024)

The high volatility of Bitcoin is one aspect that makes it a versatile tool in portfolio management. Figure 2 shows the historical price volatility of Bitcoin from 2013 to 2023. The figure illustrates the high volatility of Bitcoin's price. Tests of Bitcoin's price volatility were conducted in a study by Köse et al. (2024). According to the study, Bitcoin's price volatility is stationary at the 1% significance level. This result indicates that Bitcoin exhibits mean-reverting behavior, which is common in equity and currency markets.

Furthermore, the limited availability of Bitcoin differentiates it from many financial assets. The maximum number of bitcoins that will be created is 21 million bitcoins, and as of September, around 19.9 million bitcoins have been mined. (Coinbase). The release rate of bitcoins is strictly controlled by a built-in mechanism called the halving mechanism. The halving mechanism sets a controlled pace in which the mining reward for Bitcoin is cut in half Every four years. Cutting the reward slows the number of bitcoins that enter the circulation. The maximum capacity of Bitcoins in circulation will be reached around the year 2140.

The unique characteristics of Bitcoin complicate its placement in financial markets, and Bitcoin's classification has been a problem since its introduction in 2009. A study by Dyhrberg (2015) addresses this problem. According to Dyhrberg, Bitcoin is positioned

between gold and commodities. The placement between gold and commodities is explained as it performs well against stock market, and it serves as an effective hedging instrument. The continuous availability and high trading frequency allow market participants to react quickly and reduce market risk. Furthermore, Bitcoin can be used to hedge against currencies, which gives it a unique role in the markets.

The view of Bitcoin as a hybrid asset, which shares the elements of commodities and currencies, is supported by multiple studies. For instance, a study by Bouri et al. (2016) shows that Bitcoin exhibits safe-haven behavior. This behavior appeared before a major market crash, but Bitcoin lost this quality afterward. A study by Bouri et al. (2020) reports that Bitcoin can serve as a safe haven for stock markets. According to the study, Bitcoin outperformed established hedges, such as gold and commodity indexes, during certain periods. Furthermore, a study by Klein et al. (2018) concludes that Bitcoin and gold share asymmetric responses to market shocks. According to the study, during market stress, Bitcoin tends to outperform gold. This differentiates it from gold, which maintains its stability during market stress.

Based on the findings introduced in this chapter, Bitcoin can be seen as a hybrid asset. It combines certain safe-haven elements with features of precious metals that have high volatility. The combination highlights the possibilities of Bitcoin in portfolio management, as it can serve as a portfolio diversifier and help manage risks.

4 Bitcoin Options

Bitcoin options are a relatively new segment of the derivatives market. Bitcoin options provide instruments for hedging and speculation on the world's largest cryptocurrency. They share the same contractual structure as traditional options but differ significantly from equity or index options. The differences are mainly related to their volatility, trading venues and market participants. These differences create both opportunities and challenges for market participants.

4.1 Structure and Development of the Bitcoin Options Market

The first clear difference between the Bitcoin and classic equities is volatility. Based on findings analyzed in this paper, the Bitcoin market is far more volatile than traditional assets. According to Nzokem and Maposa (2024), between 2020 and 2024, the realized volatility of Bitcoin was approximately four times higher than the volatility of major equity indices in the long run. This is reflected in the implied volatilities, which affect the pricing of Bitcoin options.

Research by Zulfiqar and Gulzar (2021) further examines the volatility of Bitcoin options. According to findings, short-maturity Bitcoin options exhibit distinct volatility smiles and skews. Volatility smiles and skews are hard to capture by using classical pricing models which indicates difficulties in their use of pricing Bitcoin options. The complexity of Bitcoin as an asset is further complicated by the underlying market structure.

Another problematic aspect of the Bitcoin options market relates to the trading platforms where Bitcoin options are traded. Bitcoin options are primarily traded on platforms that are mostly used to trade cryptocurrencies. Platforms such as Deribit and Binance dominate the global volumes of the cryptocurrency derivatives market. Compared to markets where equity and index options are traded, they are more fragmented and much less regulated. This can lead to difficulties that include weaker protection of investors and lower transparency.

The differences influence the participant base of the Bitcoin options market. The cryptocurrency derivatives market, including the Bitcoin option market, attracts a mix of different traders, but institutional participation is low compared to traditional equity and index markets. In order to increase institutional participation, the efficiency of Bitcoin options markets needs to improve, and such participation is expected to grow in the future. For example, Chicago Mercantile Exchange (CME) is expected to open 24/7 cryptocurrency derivatives trading in early 2026 (CME). This indicates that Bitcoin options markets are evolving, and growing demand is expected. The participation base is changing toward a more institutional investor base. Due to this, informational efficiency of Bitcoin options can improve.

Overall, the Bitcoin options market differs from traditional options markets due to high volatility, lower transparency, and weaker investor protection, which is caused by less regulated exchanges. However, based on the findings introduced in this chapter, the efficiency of the Bitcoin options market is expected to grow due to upcoming changes in its market.

5 Option Pricing

According to D'Uggento et al. (2025), accurate option pricing is essential for all market participants, and the need is pronounced in continuously evolving markets. The need for accurate option pricing is highlighted when making investment decisions and managing risks. Inaccurate option pricing can lead to inefficiencies in markets and financial losses.

5.1 Volatility

One of the key concepts in option pricing is volatility. Volatility measures uncertainty and financial risk, as it measures the price variation over time. Hull (2021) states that volatility can be categorized as historical or implied volatility. Historical volatility is calculated from past price data, and it offers a reference point for evaluating an asset's price variability. Historical volatility does not capture future movements in volatility. Implied volatility, on the other hand, is a forward-looking volatility. It is calculated from option market prices, and it reflects market expectations of future price fluctuations. Due to Bitcoin's high volatility, price swings, and speculative trading behavior, implied volatility is considered more relevant in pricing Bitcoin options.

Furthermore, volatility can be stochastic. Stochastic volatility refers to the random changes in volatility over time. The nature of this volatility can make it a useful tool for more advanced option pricing models. In contrast to historical volatility, stochastic volatility models such as Heston and GARCH models allow volatility to change dynamically. Considering the characteristics of Bitcoin options, stochastic volatility can be particularly useful for pricing these options.

5.1.1 Implied Volatility

Expectations of stock volatility are usually tracked using implied volatility. The historical volatility shows past price changes, but implied volatility is derived from option market prices and reflects anticipated future price movements (Hull, 2021). Traders typically

focus on an option's implied volatility instead of its market price, since it is generally more consistent. Implied volatility from actively traded options is often used as a reference to estimate suitable volatility levels for pricing other options.

Market-wide implied volatility can be measured in multiple ways. The VIX, also known as the "fear index," is the most common measure of market-wide implied volatility. The VIX is derived from S&P 500 option prices. It rises when investors expect higher uncertainty or market turbulence. Elevated VIX often indicates fear and potential market declines, whereas low VIX indicates market stability and confidence among investors.

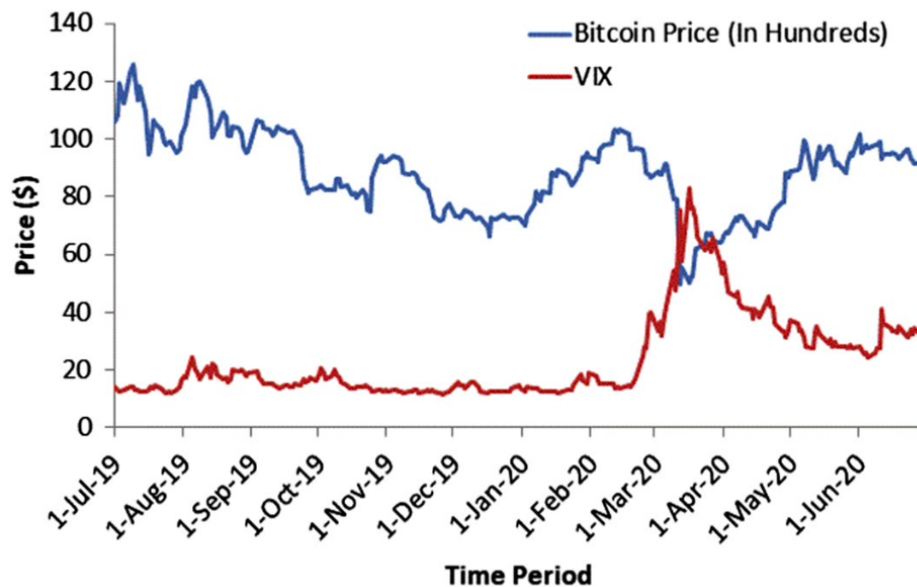


Figure 3. Evolution of Bitcoin price and VIX over time (Zulfiqar & Gulzar, 2021)

Figure 2 demonstrates the relationship between Bitcoin price and VIX over time. As shown, there is a negative correlation between Bitcoin price and VIX. This dynamic is also observed in the cryptocurrency options market. When market fear increases, meaning that the VIX rises, Bitcoin's price usually declines, as investors move away from riskier assets. When market stress is high, Bitcoin's implied volatility often climbs, indicating uncertainty and larger anticipated price movements. Conversely, when the VIX decreases, indicating market stability, Bitcoin's price often recovers, and its implied volatility decreases.

5.1.2 Volatility Smiles

A volatility smile is a graphical representation of an option's implied volatility as a function of its strike price for a given time to maturity (Hull, 2021). In some cases, this pattern is referred to as a volatility skew, which occurs when implied volatility declines as the strike price increases. Typically, options with lower strike prices, such as deep out-of-the-money puts and deep in-the-money calls, exhibit higher implied volatility compared to higher strike-price options, such as deep in-the-money puts and deep out-of-the-money calls.

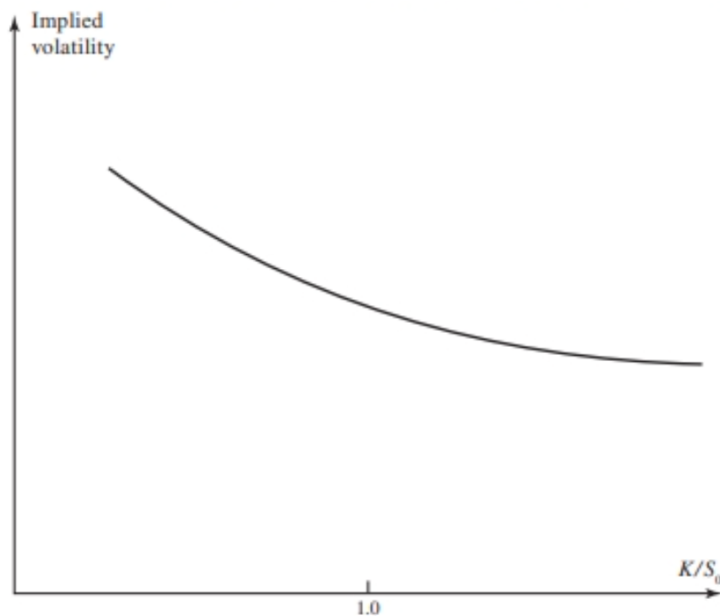


Figure 4. Volatility smile for equities (K = strike price, S_0 = current equity price). (Hull, 2021)

Figure 3 illustrates the volatility smile of equity options. Although the chart does not directly represent the volatility structure of cryptocurrency options, its applicability can be critically assessed. Hou et al. (2018) find that Bitcoin options pricing follows some patterns observed in traditional markets but is more influenced by jumps and high-frequency market activity. While the results show some level of market maturity, they also indicate difficulties in applying traditional pricing models to Bitcoin options. The study

finds that the SVCJ model (stochastic volatility with correlated jumps) shows the steepest skew. Based on this finding, it is evident that jump risks are significant factors in Bitcoin options pricing. The study also shows that differences between models are most clear for short-term options.

A study examining the volatility of Bitcoin options by Zulfiqar and Gulzar (2021), reaches the same conclusion and supports findings made by Hou et al. (2018). According to their empirical analysis, Bitcoin behaves similarly to traditional markets and is often classified as a commodity-type asset. The study also suggests that short-dated Bitcoin options exhibit high volatility near expiration. This indicates the need for more crypto-options traders.

5.2 Bitcoin Option Pricing Models

Based on findings introduced in the study so far, Bitcoin markets differ from traditional financial markets. The main reasons include the decentralized structure, lack of regulation, and speculative nature. To further support this, Hou et al. (2018) note that Bitcoin's structural characteristics make it difficult for traditional financial theories to capture its behavior. Bitcoin's characteristics influence its markets and create challenges for option valuation.

Developed option pricing models may face challenges when pricing cryptocurrency options, due to the different characteristics of cryptocurrency markets compared to more traditional markets. This chapter introduces models that are used in Bitcoin option pricing. Models that are included are the Black-Scholes model, the Heston-Nandi GARCH model, and the Merton jump-diffusion model. Furthermore, the future of option pricing is also discussed by reviewing studies on recent developments. The applicability of established models must be reviewed to ensure efficient pricing.

5.2.1 Black-Scholes Model

Since the development and introduction of the Black-Scholes model, it has become one of the foundational models in finance. It was developed in the 1970s by Fischer Black, Myron Scholes, and Robert Merton. The model provides a systematic approach for determining option values and managing risks. Due to its central role in financial theory, it is also used in the pricing of Bitcoin options, and studies have been conducted regarding this topic. The unique characteristics of cryptocurrency derivatives create challenges, which the Black-Scholes model may have difficulties in capturing.

A study investigating the performance of the Black-Scholes model in the valuation of Bitcoin options by Cao and Celik (2021) supports the view that the Black-Scholes model is not suitable for pricing Bitcoin options efficiently. The analysis is based on data covering a wide range of option maturities and moneyness levels. Results show the Black-Scholes model consistently underestimating option prices, with the underestimation notably strong for deep in-the-money contracts. Results indicate that the model's assumption of constant volatility prevents it from capturing the volatility skew seen in Bitcoin markets.

Another study examining the use of Black-Scholes model in Bitcoin option pricing by Hilliard and Ngo (2022) compares how the Black-Scholes model performs to the Merton jump-diffusion model. Results clearly show Black-Scholes performing worse. The study demonstrates that the jump-diffusion model more effectively captures sudden price movements typical of Bitcoin. Capturing jumps offers more accurate option values that are more consistent with market prices.

Furthermore, Jalan et al. (2020) compare a set of GARCH-type models, against the Black-Scholes model for Bitcoin options pricing. The results presented in their study align with other studies introduced. According to the study, stochastic volatility models are more effective than the Black-Scholes model at capturing volatility clustering and time-varying

risk. GARCH models are superior in producing more accurate option prices and enhancing hedging effectiveness.

According to studies reviewed, (Cao & Celik, 2021; Hilliard & Ngo, 2022; Jalan et al., 2020) the Black–Scholes model does not price Bitcoin options efficiently. As noted, Black-Scholes assumes lognormal price distributions and constant volatility, which are not suitable assumptions for markets like Bitcoin options. Alternative models that incorporate stochastic volatility or jump dynamics seem to work better at capturing the key elements of Bitcoin.

5.2.2 Heston-Nandi GARCH Model

Another widely used pricing model, the Heston-Nandi GARCH model (Heston & Nandi, 2000), integrates a GARCH (Generalized Autoregressive Conditional Heteroskedasticity) structure with a risk-neutral valuation approach. The model allows time-varying volatility, which offers a more accurate representation of market dynamics. Since the introduction of the Heston-Nandi GARCH model, it has been used to price options across multiple markets, including the cryptocurrency derivatives market.

A study by Siu and Elliott (2020) integrates the Heston-Nandi GARCH component with a self-exciting threshold autoregressive (SETAR) regime-switching model, and the model is used to price Bitcoin options. This approach allows the authors to incorporate both conditional heteroscedasticity and potential regime shifts in Bitcoin's price dynamics. Results show the model produces a slight implied volatility skew for short-maturity options. Findings are consistent with empirical patterns observed in Bitcoin options markets.

Venter and Maré (2021) examined the performance of the Heston Nandi GARCH model in the context of Bitcoin futures options traded on the CME. They found that a symmetric GARCH specification provided the best fit to Bitcoin futures returns and yielded model option prices close to observed market prices for most expiries. In conclusion, the option values generated by the Heston Nandi model were noticeably closer to actual market

prices compared to those produced by other models. Findings suggest the model has potential for effective price determination in the Bitcoin options market.

Furthermore, Chen and Yang (2024) study the use of GARCH-type models in Bitcoin option pricing. Based on the findings, Bitcoin options show pronounced implied volatility smiles for short-term maturities. Longer term maturities show a more smirk-like pattern. According to the study, the ARJI–EGARCH model provided the best overall results. It produced more accurate option prices compared to other models, and it outperformed the stochastic volatility model with correlated jumps. The study emphasizes the need to take time-varying jump behavior into account. According to the study, realized jump variations enhance the ability to match observed volatility structures and more accurately price the jump-risk premium on Bitcoin options.

Based on the findings introduced, the use of GARCH-based models is recommended. The Heston-Nandi framework captures the key characteristics observed in cryptocurrency markets better compared to the Black-Scholes model. Extensions of the basic model further improve the fit and explanatory power, as evidenced by the inclusion of variance risk premiums and dynamic jump components to match Bitcoin’s unique market behavior. Overall, it offers a more reliable basis for pricing Bitcoin options.

5.2.3 Jump-Diffusion Models

Another commonly used option pricing model, the jump-diffusion model, was introduced by Merton (1976). Jump-diffusion models allow the modeler to capture sudden jumps, which are unexpected and large price movements, that affect assets valuation. Jump-diffusion models often detect jumps in combination with stochastic volatility, and the combination can offer flexibility in pricing Bitcoin options, since sudden price movements are common in Bitcoin markets.

Several studies have been conducted using jump-diffusion models in pricing Bitcoin options. A study by Hilliard and Ngo (2022) shows that option prices calculated using jump

risks with convenience yield are efficient and provide more accurate values compared to the Black-Scholes model. Based on a study by Chen and Huang (2021), jumps are essential for capturing implied volatility skews seen in Bitcoin options. Furthermore, a study by Hout et al. (2020b) supports the view that jumps in volatility and returns are one of the most important factors in Bitcoin options pricing.

Overall, based on the findings, jump-diffusion models should be considered when pricing Bitcoin options. Jump-diffusion models provide a realistic representation of Bitcoin price behavior. Many studies conclude that combining jump components with stochastic volatility yields the best performance, as this approach reflects both the abrupt jumps and persistent volatility clustering that define cryptocurrency markets.

5.3 Future of Bitcoin Option Pricing

The pricing of cryptocurrency options will remain challenging in the future. Artificial intelligence–based methods are expected to create new pricing models and improve both efficiency and accuracy. In recent years, studies have been published that introduce novel approaches utilizing artificial intelligence. This section reviews two studies that examine the effectiveness of such models in pricing Bitcoin options.

Pagnottoni (2019) presents a two-stage neural network model in which the theoretical prices produced by classical methods serve as inputs for a multilayer perceptron. The dataset consists of Bitcoin options from the Deribit exchange, restricted to short maturities, and the model is evaluated both in-sample and out-of-sample. The results show that classical methods systematically underprice Bitcoin options, while the neural network significantly reduces pricing errors across all evaluation metrics. The consistency of both in-sample and out-of-sample results indicates the generalizability of the approach. These findings support the use of data-driven and flexible models in situations where market structure changes, volatility shifts, and smile or skew effects weaken the performance of parametric models.

Pagnottoni (2019) further suggests that future research could benefit from using high-frequency data. Brini and Lenz (2024) compare traditional pricing models (Black–Scholes and Heston) with two machine learning models in the pricing of cryptocurrency options. Their study incorporates realized volatility estimators based on high-frequency data as explanatory variables. The dataset includes transactions of BTC and ETH options from Binance between 4 August and 18 November 2022, with equity options used as a comparison. The results show that the machine learning models, particularly XGB, deliver substantially lower pricing errors and higher explanatory power than Black–Scholes and Heston. Traditional models systematically underprice cryptocurrency options and exhibit considerable bias of around 40 percent. Equity options prove easier to price than cryptocurrency options in the dataset, reflecting the higher volatility, fragmentation, and inefficiencies of crypto markets.

Based on studies reviewed, machine learning applications are well suited to capture volatility structures in cryptocurrency markets. More studies should focus on this topic in the future, since AI is developing fast and it will offer opportunities in terms of option pricing. Data-driven approaches offer potential improvements in option pricing, which is crucial for market development.

6 Analysis and Discussion

This chapter focuses on discussing the hypotheses introduced at the beginning of the study. Based on the findings, it can be concluded that H1 is true. According to studies, Bitcoin's volatility is significantly higher compared to traditional financial instruments. Further supporting this view, analysis by Nzokem and Maposa (2024) demonstrates that only 40.32% of Bitcoin's daily returns fall within a $\pm 1.06\%$ – $\pm 1.23\%$ range, compared to 80.05% for the S&P 500. The results show that Bitcoin's average value-at-risk is approximately four times higher compared to the value-at-risk of the S&P 500. This finding confirms that Bitcoin's return distribution has heavier tails and a substantially higher probability of extreme price swings.

Bitcoin option prices are underestimated by models that assume constant volatility, which is shown in studies by Cao and Celik (2021) and Hilliard and Ngo (2022). Findings highlight that the volatility of Bitcoin is higher compared to most financial instruments, and this creates challenges in pricing the options. Due to the high volatility, more advanced option pricing models, which capture jumps and changing volatility, are preferred.

The findings regarding the high volatility of Bitcoin help explain the inefficiencies in Bitcoin options markets. A study by Alexander et al. (2024) shows that inefficiencies in Bitcoin derivatives are most notable during periods of heightened volatility. Similarly, a study by Sözen (2025) shows that the volatility of cryptocurrencies is highly persistent and asymmetric. This indicates that market shocks can create instability that sustains inefficiencies over time.

Findings also support H2. Based on studies, informational and arbitrage efficiencies in cryptocurrency options remain behind those of equity or currency options. To support this view, Alexander et al. (2024) tested basic arbitrage conditions in the Bitcoin derivatives market, and clear inefficiencies were found, especially during the market's earlier years.

Informational efficiency may be the main reason why the Bitcoin option market is not as efficient. Informational efficiency of cryptocurrency markets can improve when trading occurs under more regulated and liquid conditions, as suggested by a study from Nimalendran et al. (2024). Based on findings, regulatory oversight and increased institutional participation could help cryptocurrency markets become more efficient compared to traditional financial markets. This suggests that inefficiencies in the Bitcoin options market can be mainly structural, not due to the nature of asset itself.

Bitcoin options markets are less efficient, and volatility of Bitcoin remains high, but studies report positive progress. Efficiency is improving as liquidity continues to increase, trading infrastructure evolves, and institutional participation grows. Studies by both Alexander et al. (2023, 2024) and Chen and Yang (2024) support this view, forecasting that efficiency will improve as the market matures.

7 Conclusion

This study has explored the pricing and efficiency of Bitcoin options. Based on the review of multiple studies, the volatility of Bitcoin is a crucial factor in option pricing. As the volatility remains high, the Bitcoin options market lags behind the efficiency measured in traditional markets. The characteristics of Bitcoin are complex, which creates challenges for pricing the options.

Pricing of Bitcoin options remains problematic. Based on the reviewed studies, more advanced models, such as GARCH specifications and jump diffusion, are recommended. Furthermore, the possibilities of artificial intelligence-based models must be considered, since studies using AI offered have offered optimistic insights. To further enhance the accuracy of pricing and market efficiency, future research should focus on the application of AI-driven models in Bitcoin options pricing.

The efficiency of Bitcoin options markets continues to evolve as arbitrage opportunities have declined, and liquidity has improved. Inefficiencies remain, due to high volatility and less-regulated market conditions. In more mature markets, these inefficiencies would be eliminated more quickly. Informational efficiency remains uneven, but the growth of institutional participation and the use of more regulated platforms support the shift toward greater market efficiency.

The limitations of the study should be acknowledged. The analysis relies on secondary literature. Therefore, the study may not capture the most recent market developments in cryptocurrency markets. Furthermore, the lack of long-term historical data for Bitcoin options limits the overall coverage of the conducted research. Future research should consider further investigating the application of machine learning models in option pricing, and informational efficiency. The launch of CME's 24/7 cryptocurrency derivatives markets in the future may offer new insights into how the informational efficiency of Bitcoin options changes, as more regulated platforms enter the market.

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Note: AI was used to enhance the grammar and clarity of the text.

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