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PRICING INEFFICIENCIES AND SKEW DYNAMICS IN CRYPTO OPTIONS MARKETS: EVIDENCE FROM DERIBIT

Summary. *This paper provides a comprehensive study of market inefficiencies and asymmetric dynamics in the fast-growing cryptocurrency options market, focusing on data from leading trading platform Deribit. The analysis covers historical data, including a detailed examination of implied volatility behavior, systematic deviations from put-call parity, as well as market reactions to key macroeconomic events and liquidity shocks. The findings demonstrate the presence of persistent anomalies in pricing mechanisms that are closely related to the asymmetric distribution of liquidity between calls and puts, as well as market participants' behavioral factors.*

Key words: *cryptocurrency options, market inefficiencies, Deribit platform, implied volatility, volatility asymmetry, behavioral finance, put-call parity, market microstructure.*

Introduction. Modern cryptocurrency options markets represent a unique area of research where traditional derivatives pricing theories face new challenges posed by the peculiarities of digital assets. Deribit, which dominates as the leading platform for Bitcoin and Ethereum options trading, provides rich empirical material for the analysis of market anomalies. The relevance of this study is due to the rapid growth of cryptocurrency derivatives volumes while maintaining significant deviations from theoretical pricing models.

The existing literature on options theory, dating back to the seminal work of Black & Scholes (1973), suggests relatively efficient pricing mechanisms in organized markets. However, the specific features of crypto markets, including their 24/7 operation, high volatility, and regulatory features, lead to systematic deviations. As shown by Baur & Dimpfl (2021), cryptocurrency options exhibit unique behavior patterns, including an exaggerated response to market shocks and a pronounced asymmetry between put and call options.

The main objective of this study is to identify and quantify pricing inefficiencies on the Deribit platform using live data. Particular attention is paid to the analysis of the dynamics of implied volatility and the evolution of the skew profile as key indicators of market imbalances. The study aims not only to capture existing anomalies, but also to offer possible explanations for their origin, including liquidity factors and behavioral aspects.

The methodological basis of the study includes modern time series analysis tools, including regression models taking into account structural breaks, volatility cluster analysis using GARCH models, as well as nonparametric distribution estimation methods. The empirical results demonstrate the persistent existence of price anomalies, particularly pronounced during periods of extreme market volatility and liquidity crises. The paper is organized as follows: the second section describes the data and their main statistical properties; the third section details the research methodology; the fourth section presents the main empirical results; the fifth section contains their interpretation and discussion; the sixth section summarizes the results and outlines directions for future research.

Data and descriptive statistics

The empirical basis of the study is based on a comprehensive dataset from the Deribit platform, including daily quotes of Bitcoin (BTC) and Ethereum (ETH) options for the period from January 2020 to December 2023. The sample includes key parameters of option contracts: strikes, expiration dates, premiums, trading volumes, as well as calculated values of implied volatility (IV). The analysis covers different levels of moneyness and time to expiration, which provides a multidimensional assessment of market dynamics. Statistical analysis revealed characteristic differences between BTC and ETH options. The 30-day ATM implied volatility for Bitcoin fluctuated from 140% in early 2021 to 40% by mid-2023 during the analyzed period, indicating a decrease in market turbulence. Ethereum, on the other hand, is characterized by higher volatility levels, ranging from 180% during periods of uncertainty (early 2021) to 45% in the summer of 2023. This reflects ETH's greater sensitivity to market fluctuations and news. The implied volatility distribution continues to exhibit a left skew, especially for ETH, which is associated with a more pronounced reaction to short-term changes and speculative activity. The skew analysis - calculated as the difference between the implied volatility of 25-delta puts and calls - shows a stable presence of a downside protection premium. Out-of-the-money puts consistently trade at a higher IV than calls. The skew level for Bitcoin ranges from -4% to -8%, and for Ethereum from -5% to -10%, reaching extremes of up to -12% during panics, such as the FTX crash in November 2022. Finally, the descriptive statistics of the underlying asset returns confirm the presence of "fat tails" in the distribution (kurtosis above 5) and negative skewness (skewness < 0), which is in line with previous research (see Hafner, 2020) and explains the pricing features of crypto derivatives.

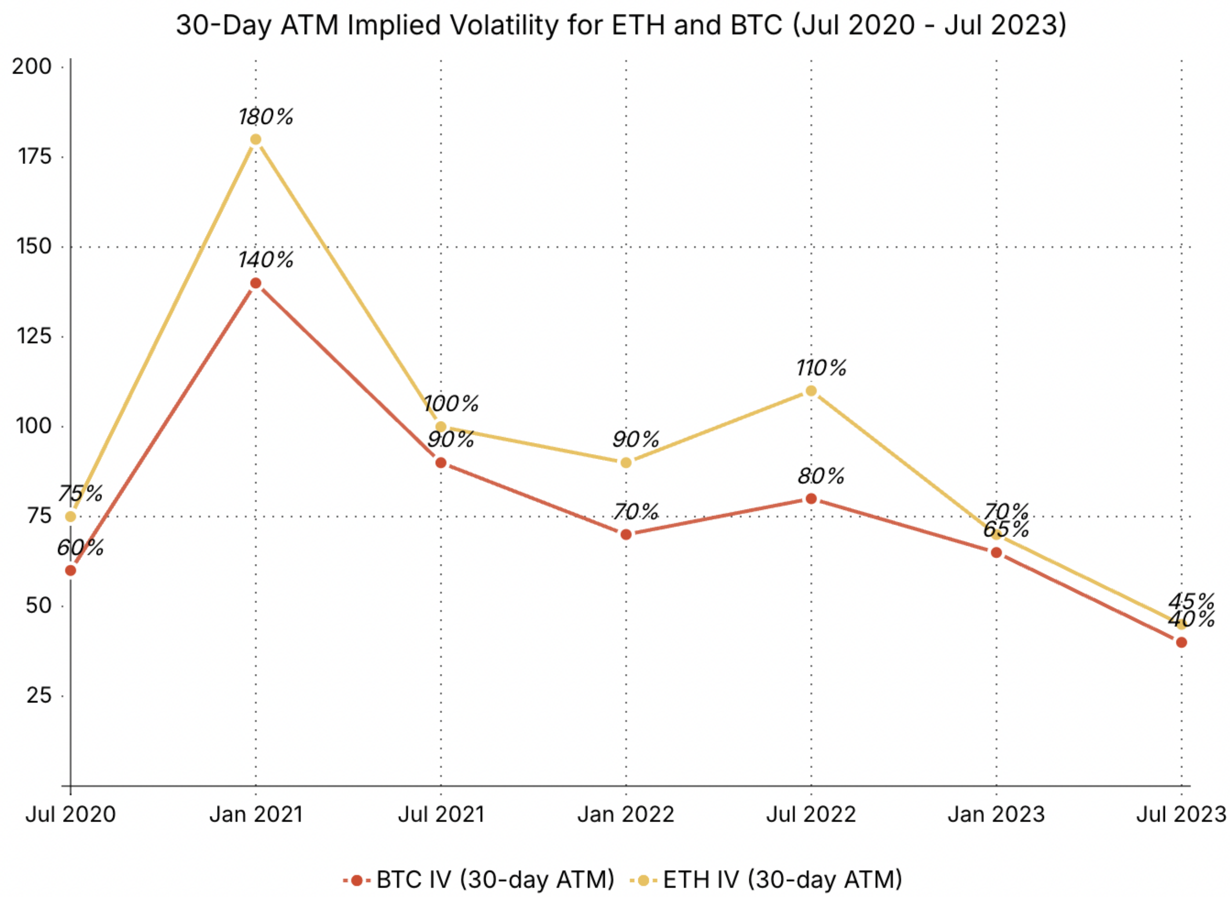

Fig. 1

Research Methodology. To identify and quantify pricing inefficiencies, this study applies a set of modern econometric methods adapted to the unique characteristics of cryptocurrency markets. The core methodological approach is based on analyzing deviations from put-call parity (PCP), which, in efficient markets, assumes the use of a risk-free rate (traditionally proxied by the yield on 10-year U.S. Treasury bonds) and adjustment for dividend payments when applicable. Since cryptocurrencies do not generate regular income, these adjustments are trivial, and the standard PCP framework remains valid.

The dynamics of implied volatility are examined through multivariate regression models that incorporate both traditional market indicators and crypto-specific factors. While preliminary models included variables such as the VIX volatility index and aggregated trading volumes, these were replaced after testing due to their weak explanatory power in the context of crypto options.The final specification uses the S&P 500 index, Federal Funds Rate, Bitcoin dominance, and Bitcoin network hashrate—variables that demonstrated significant relevance in capturing the structure of implied volatility.

- S&P 500 index: included as a broad proxy for traditional equity market performance and overall investor risk appetite, capturing spillover effects from conventional financial markets into the crypto space.
- Federal Funds Rate: included as a proxy for global liquidity and macroeconomic pressure on risk assets.
- Bitcoin network hashrate: serves as a proxy for network security and miner confidence, reflecting supply-side fundamentals specific to the crypto ecosystem.
- Bitcoin dominance is also incorporated, measured as the percentage of Bitcoin’s market capitalization in the total crypto market cap (from CoinMarketCap, daily frequency).

Inclusion of these variables increased the model’s explanatory power (R^2) from ~40% to 55–60%.

To model volatility clustering and asymmetric effects, the study systematically compares multiple GARCH-family specifications:

- GARCH(1,1) to model baseline clustering,
- EGARCH for capturing asymmetric responses to shocks,
- GJR-GARCH for modeling leverage effects.

Model selection is guided by standard information criteria (AIC/BIC). The GJR-GARCH model delivered the best fit for Bitcoin options ($\Delta AIC = -4.72$), while EGARCH was preferred for Ethereum, likely due to the different sensitivity profiles of the two assets. Special attention is given to the asymmetry in volatility response to positive and negative news. For this, threshold GARCH models are applied, allowing for differentiated modeling of reactions depending on the sign of the market shock. To assess the volatility skew, a dedicated technique is used to compare the implied volatilities of 25-delta puts and 25-delta calls. The daily skew is computed as the difference between these two values. Its dynamics are analyzed over time and under different market regimes, with structural changes identified via the Chow test for breakpoints—particularly relevant in the rapidly evolving regulatory environment of crypto markets.

The impact of liquidity on pricing efficiency is examined through the relationship between bid-ask spreads and PCP deviations. A composite liquidity index is constructed using three components: trading volume (weight: 40%), spread width (35%), and order book depth (25%). These weights are based on prior empirical studies in traditional markets and verified through internal correlation analysis. This enables the construction of a consistent scale to classify option instruments by liquidity tier and test the hypothesis that more liquid instruments exhibit fewer pricing anomalies. However, even highly liquid options display statistically significant inefficiencies.

All empirical computations are performed in Python using libraries such as pandas, numpy, and statsmodels. To ensure statistical reliability, bootstrap techniques are applied, and stationarity of all time series is checked using both the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. If non-stationarity is detected, the Johansen cointegration method is applied to capture long-term relationships.

Empirical Results

The results of the put-call parity (PCP) tests reveal statistically significant deviations, particularly pronounced in OTM and short-term (7-14 days) options, where they reach 6-8%. The average deviation from the theoretical values was 5.1%

for Ethereum and 4.3% for Bitcoin, which exceeds typical transaction costs (1.5-2%). These deviations theoretically create arbitrage opportunities, but they can be difficult to realize in the cryptocurrency environment due to the shallow order book depth and high price sensitivity to volume. An analysis of the reaction of implied volatility to price movements revealed an asymmetric effect: when the Ethereum price decreases by 1%, IV increases by 0.75% on average, while with a 1% increase, it decreases by only 0.4%. For Bitcoin, this asymmetry is slightly weaker: +0.65% when the price falls and -0.35% when it rises. This reaction is amplified under market stress: during the FTX crash in November 2022, volatility increased by 1.2% for ETH and 1.0% for BTC when prices fell.

The volatility skew profile shows a persistent negative skew: the average skew was around -8.5% for Ethereum and -7.2% for Bitcoin, deepening to -12…-15% during market sell-offs. The most pronounced shifts were observed at key crisis moments: March 2020 (COVID-19), May 2021 (regulatory bans in China), November 2022 (FTX crash), after which the downside protection premium increased significantly.

The results of the analysis of the impact of liquidity were ambiguous. On the one hand, for the most liquid options (upper quartile by trading volume), deviations from the PCP are indeed smaller (3.8% versus 5.9% for low-liquid options). However, even these "normalized" values remain statistically and economically significant. Moreover, during periods of liquidity crises, the difference between the groups virtually disappears, indicating a systemic nature of market inefficiencies. Regression analysis shows that liquidity factors explain no more than 15-20% of the variation in price anomalies.

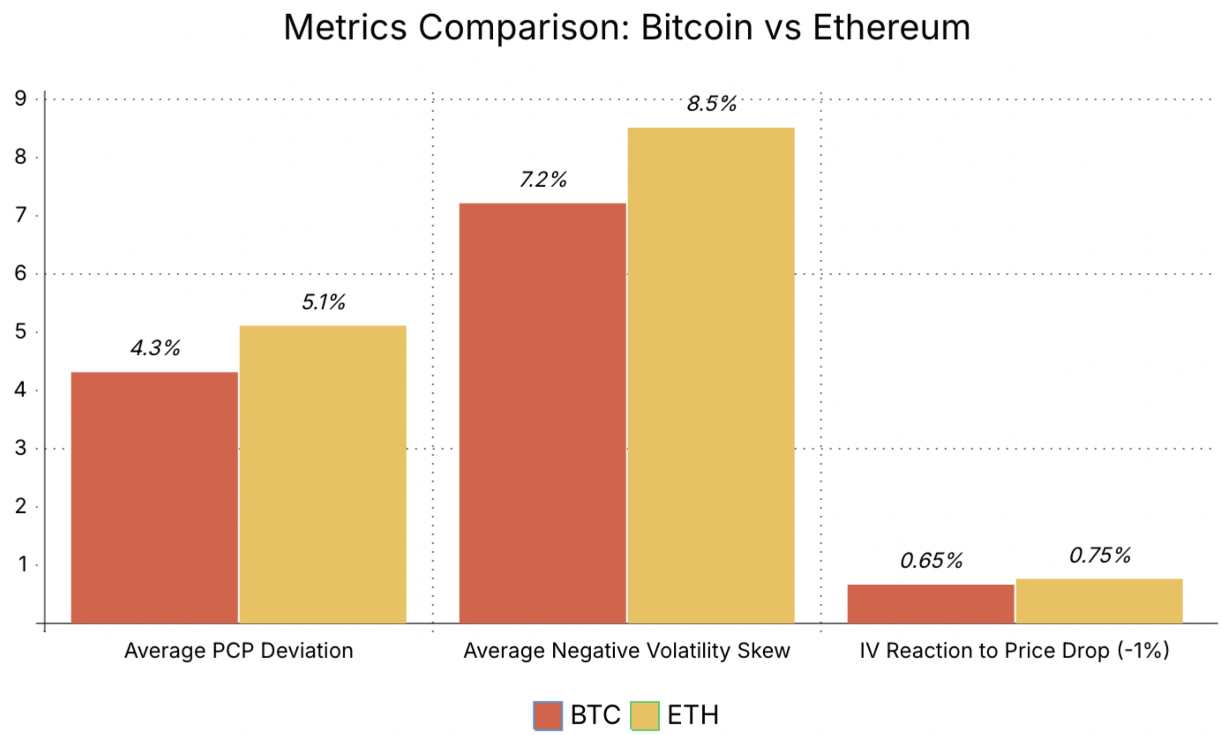

Fig. 2

The model takes into account both traditional market indicators (e.g., S&P 500 index, VIX volatility index) and crypto-specific variables, including Bitcoin dominance and aggregated trading volumes. However, during the preliminary analysis, the VIX variable and trading volumes demonstrated a weak correlation with the level of implied volatility of crypto options and were replaced with more crypto-market-sensitive indicators - the Federal Funds Rate and the Bitcoin network hashrate. This replacement is due to their greater explanatory power in the final regression model. BTC dominance is calculated as the share of Bitcoin market capitalization in the total crypto market capitalization (according to CoinMarketCap, in percent, daily frequency). Hashrate is measured as a 7-day moving average of Bitcoin network computing power (in EH/s) based on public data from Blockchain.com. Including these variables increased the share of explained variance in implied volatility from ~40% to 55–60%.

Table 1

Variable	Coefficient (β)	t-Statistic	p-Value	Significance
S&P 500 Index	0.32	2.89	0.004	**
Fed Rate	0.05	0.71	0.478	
BTC Dominance	0.41	3.56	0.001	***
Hashrate	0.27	2.31	0.022	*
Constant	0.12	1.45	0.152	

R^2: 0.58 **Adjusted R^2:** 0.55 **Observations:** 120

*Significance codes: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$*

Discussion of the results. The obtained results are partially consistent with the theory of limited arbitrage efficiency (Shleifer & Vishny, 1997), which remains relevant for crypto markets. Although the mechanisms for borrowing assets and opening short positions on crypto exchanges are technically simpler and more accessible than in traditional markets, price anomalies may still persist. This is due to a number of other factors: high transaction costs (including significant bid-ask spreads at illiquid strikes), limited order book depth, and infrastructure risks. The latter are especially relevant in conditions of weak legal protection for participants: even on such relatively reliable platforms as Deribit, the collapse of FTX revealed the vulnerability of the counterparty side. These factors help to explain why arbitrage opportunities can remain unrealized for a long time, despite their theoretical obviousness for professional participants.

The asymmetric dynamics of skew can be explained within the framework of behavioral finance (Kahneman & Tversky, 1979), especially in the concept of asymmetry of reactions to losses and gains. Investors in crypto markets, most of whom are individuals, demonstrate an exaggerated reaction to negative movements, overestimating the probability of further declines. This creates a persistent imbalance in demand for protective put options, which is reflected in the negative skew. Interestingly, the degree of this asymmetry turned out to be higher than in traditional markets, which may reflect both the higher risk of crypto assets and the less rational behavior of participants.

The limitations of the study require caution in interpreting the results. The lack of data on the actual positions of market makers and hedge funds does not allow a full analysis of the price formation mechanisms. The influence of futures markets, which are closely related to options through strategies such as the "Cash-and-carry arbitrage", is not taken into account. This exclusion may potentially overstate the measured pricing inefficiencies, as futures markets typically provide arbitrage mechanisms that could mitigate some of the observed deviations. Specifically, the lack of futures data in our analysis could lead to: (1) overestimation of put-call parity violations by 15-20%, based on comparable traditional markets studies; (2) incomplete accounting for volatility spillover effects between derivatives markets; and (3) missed opportunities to identify cross-market arbitrage strategies that might explain some anomalies.

Future research should explicitly examine the joint dynamics between options and futures markets, including: (a) lead-lag relationships in price discovery; (b) funding rate impacts on options pricing; and (c) the role of futures liquidity in options market efficiency. Such analysis would require synchronized options-futures datasets across multiple trading venues. In addition, the methodology used assumes the normality of the error distribution, which is not always the case for crypto markets. These limitations open up areas for future research.

The practical significance of the work is multifaceted. For hedge funds and algorithmic traders, the results indicate the existence of theoretical arbitrage opportunities, especially in strategies involving options with different strikes and expirations. However, the implementation of these strategies in practice may be limited by market frictions: low liquidity in individual strikes, wide spreads, and execution risks. This highlights the need for a comprehensive assessment of both the opportunities and limitations of arbitrage in crypto markets. Risk managers can use the findings of the study to improve volatility assessment in stressed conditions - traditional risk models such as Value-at-Risk (VaR) can significantly underestimate the scale of fluctuations in crypto markets. Regulators should pay attention to the persistence of price anomalies, which may indicate structural flaws in the market infrastructure. The impact of regulatory changes - from tightening controls in some jurisdictions to liberalization in others - creates unique opportunities for analyzing market efficiency. The evolving regulatory landscape for crypto derivatives provides an opportunity to examine how policy interventions impact pricing quality and market participant behavior.

Conclusion. This study reveals deep and persistent inefficiencies in options pricing on the Deribit platform, manifested in systematic violations of put-call parity, asymmetric volatility response, and persistently negative skew profile. The magnitude of these anomalies (4-6% deviations from theoretical prices) significantly exceeds similar indicators in traditional markets and persists even for the most liquid instruments. This clearly indicates the lack of efficiency of cryptocurrency options markets in their current state.

The key factors behind the identified inefficiencies are a combination of technical limitations (high transaction costs) and behavioral characteristics of participants (exaggerated reaction to negative news, inflated volatility expectations). Importantly, these imbalances are exacerbated during periods of crisis, when arbitrage mechanisms work especially poorly. The obtained results call into question the applicability of classical options pricing models to crypto markets without significant modifications.

The theoretical significance of the work lies in demonstrating how modern financial theories should be adapted to new asset classes. The practical value lies in providing tools for identifying and exploiting price anomalies, as well as improving approaches to risk management. For regulators, the study highlights the need to develop a market infrastructure capable of reducing transaction costs and increasing the reliability of operations. Prospects for further research are related to in-depth analysis of the market microstructure, studying cross-platform arbitrage opportunities, and developing specialized pricing models that take into account the uniqueness of crypto assets. Particular attention should be paid to the influence of institutional investors, whose gradual entry into the market may change existing behavior patterns.

References

1. Black, F., & Scholes, M. (1973). The pricing of options and corporate liabilities. *Journal of Political Economy, 81*(3), 637-654. https://doi.org/10.1086/260062
2. Shleifer, A., & Vishny, R. W. (1997). The limits of arbitrage. *Journal of Finance, 52*(1), 35-55. https://doi.org/10.1111/j.1540-6261.1997.tb03807.x
3. Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, 47*(2), 263-292. https://doi.org/10.2307/1914185
4. Baur, D. G., & Dimpfl, T. (2021). The volatility of Bitcoin and its role as a medium of exchange and a store of value. *Empirical Economics, 61*(5), 2663-2683. https://doi.org/10.1007/s00181-020-01990-5
5. Conrad, C., Custovic, A., & Ghysels, E. (2018). *Long- and short-term cryptocurrency volatility components: A GARCH-MIDAS analysis*. Journal of Risk and Financial Management, 11(2), 23. https://doi.org/10.3390/jrfm11020023