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The Relationship Between Spot and Future Cryptocurrencies: A VECM and GARCH Approaches

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Abstract

Background and Objectives: The rapid expansion of cryptocurrency derivatives markets has fundamentally reshaped price formation, risk transmission, and informational efficiency in digital asset ecosystems. Among these assets, Bitcoin occupies a dominant position, with spot and futures markets jointly influencing trading behavior, volatility dynamics, and inflationary spillovers into broader financial systems. While economic theory predicts a close linkage between underlying assets and their derivatives, the nature of this relationship in cryptocurrency markets remains complex due to extreme volatility, fragmented trading venues, and the absence of a centralized regulatory framework. Existing empirical studies provide mixed evidence on whether Bitcoin futures stabilize spot markets through improved price discovery or amplify volatility through speculative trading, particularly during crisis episodes. Moreover, much of the literature examines long-run equilibrium, short-run dynamics, or volatility spillovers in isolation, without integrating these dimensions within a unified analytical framework. Against this background, this study aims to investigate the short- and long-run relationships between Bitcoin spot and futures markets, to assess their roles in price discovery and volatility transmission, and to examine how major crisis episodes—specifically the COVID-19 pandemic and the Silicon Valley Bank (SVB) event—affect market connectedness.

Methodology: The study employs daily data on Bitcoin spot and futures prices spanning the period from December 29, 2017, to February 18, 2025. The empirical analysis follows a multi-stage econometric strategy. First, unit root and cointegration tests are conducted to establish the time-series properties of the data and the existence of a long-run equilibrium relationship. A Vector Error Correction Model (VECM) is then estimated to capture both long-run cointegrating relationships and short-run adjustment dynamics, allowing for an explicit assessment of price discovery roles between spot and futures markets. To further explore time-varying interdependence and volatility spillovers, a two-step volatility framework is adopted. In the first step, a BEKK-GARCH model is used to model the dynamic variance–covariance structure and to extract conditional correlations between spot and futures returns. In the second step, these correlations are analyzed using a GJR-GARCH specification to capture asymmetric volatility effects and to quantify the impact of crisis episodes through event-specific dummy variables. This integrated approach enables a comprehensive examination of mean dynamics, volatility transmission, and crisis sensitivity within a single analytical framework.

Key Findings: The empirical results provide strong evidence of a stable long-run cointegrating relationship between Bitcoin spot and futures prices, indicating that the two markets are closely linked over time. Short-run dynamics reveal a clear asymmetry in adjustment behavior: deviations from the long-run equilibrium are primarily corrected through movements in the spot market, while the futures market plays a leading informational role, consistent with its function in price discovery. Volatility analysis uncovers significant and persistent bidirectional spillovers between spot and futures markets, suggesting a high degree of dynamic interdependence. The estimated GARCH parameters indicate strong volatility persistence and pronounced asymmetric effects, whereby negative shocks exert a larger and more persistent influence on market connectedness than positive shocks of similar magnitude. Crisis-specific analysis shows that the COVID-19 pandemic significantly weakened spot–futures connectedness, reflecting heightened uncertainty and structural disruption during periods of systemic stress. In contrast, the SVB episode does not exhibit a statistically significant impact on market interdependence, suggesting that not all financial disturbances transmit uniformly to cryptocurrency markets.

Policy Implications: The findings highlight the need for regulatory and supervisory frameworks that explicitly account for the interconnected and state-dependent nature of cryptocurrency markets. Given the leading role of futures markets in price discovery, enhancing transparency, liquidity oversight, and information disclosure in derivatives trading platforms is essential for maintaining orderly market functioning. The strong persistence and asymmetry in volatility spillovers further underscore the importance of real-time monitoring systems capable of identifying and mitigating the amplification of adverse shocks. During periods of heightened uncertainty, policy interventions should focus on stabilizing market expectations and limiting excessive speculative behavior that may exacerbate volatility transmission between spot and futures markets. More broadly, the results suggest that effective oversight of cryptocurrency markets requires adaptive, state-contingent regulatory approaches that recognize nonlinear dynamics and crisis-sensitive transmission mechanisms, thereby supporting market stability without stifling financial innovation.

Keywords: Bitcoin Spot and Futures; Price Discovery; Market Connectedness; VECM; Volatility Spillovers

JEL Classification Codes: G1; G13; G15; C32

1. Introduction

The emergence of cryptocurrency derivatives has been driven by Bitcoin's rapid growth, high risk profile, and dominant position in the digital asset market. These contracts exhibit several distinctive features, including relatively low storage costs, pricing mechanisms driven by supply and demand, and the absence of external price-setting intervention.

The introduction of futures contracts enables market participants to gain simultaneous exposure to both spot and derivatives markets by exploiting price differentials between spot and futures prices through so-called "cash-and-carry" strategies. Such strategies create arbitrage opportunities that may generate near risk-free returns, thereby underscoring the importance of market interconnectedness and the need to examine the dynamics linking spot and futures markets.

More broadly, the launch of cryptocurrency futures has profoundly reshaped the structure and functioning of crypto markets in terms of liquidity, volatility, and price discovery. These derivative instruments allow investors to take positions on the future value of cryptocurrencies without holding the underlying asset, thereby strengthening the interaction between spot and futures markets. As a result, futures markets facilitate a wider range of investment strategies and expand market participation.

According to the Commodity Futures Trading Commission (CFTC), the first Bitcoin futures contracts were self-certified for trading by the Chicago Mercantile Exchange (CME) and the Chicago Board Options Exchange (CBOE) in late 2017. Since their introduction, the evolution of Bitcoin futures and their linkage with spot markets have attracted substantial attention from both researchers and market participants. This interest has intensified as Bitcoin futures trading volume surged by the end of 2024, exceeding USD 20 million (CME, 2025).

Although the existence of a relationship between an underlying asset and its derivatives market is generally expected—particularly in the presence of market frictions—the nature and duration of this relationship, its mutual explanatory power, and its dynamic behavior during crisis periods remain open empirical questions.

A growing body of empirical literature documents varying degrees of connectedness between Bitcoin spot and futures markets. Bouoiyour and Selmi (2019) show that the announcement of Bitcoin futures prices led to an immediate price increase accompanied by a rise in systemic risk. Conlon et al. (2024) argue that the volume–volatility causality between Bitcoin futures and spot markets remains unresolved. Dangi (2023) extends the analysis to Bitcoin, Ethereum, and Litecoin over the period from June 2018 to June 2022, employing unconditional correlation measures, Johansen cointegration tests, VECM, and Wald block exogeneity tests. The study finds evidence of long-run unidirectional causality from futures to spot markets and short-run bidirectional causality, suggesting an evolving and state-dependent interdependence.

The remainder of this paper is organized as follows. Section 2 reviews the related literature. Section 3 presents the preliminary analysis, including data description, stationarity tests, and descriptive statistics. Section 4 examines short- and long-run dynamics using a vector error correction model (VECM). Section 5 investigates dynamic connectedness and crisis effects through a two-step empirical modeling approach. Section 6 concludes, and Section 7 discusses the policy implications.

2. Literature Review

Since their inception, cryptocurrency futures have attracted substantial academic and policy attention, largely due to the rapid growth and pronounced volatility of their underlying spot markets. As cryptocurrencies have become increasingly integrated into the global financial system, understanding the relationship between spot and derivatives markets has emerged as a central research theme. The introduction of cryptocurrency futures has raised fundamental questions regarding market access, price stability, and the strategic behavior of market participants—particularly given evidence that Bitcoin prices are driven by factors beyond trading volume alone (Aliyu et al., 2025).

A first strand of the literature examines the impact of futures introduction on spot market volatility and returns. Corbet et al. (2018) analyze changes in Bitcoin spot price volatility following the launch of futures contracts and report an increase in volatility, raising concerns about the destabilizing effects of derivatives. In contrast, Hattori and Ishida (2021) argue that the introduction of Bitcoin futures did not trigger a crash in the spot market at the end of 2017. Jalan et al. (2021), however, find that Bitcoin futures exerted a downward impact on USD-denominated Bitcoin spot returns. These mixed findings suggest that the volatility effects of futures introduction may depend on market conditions and institutional settings.

Related studies further document conflicting evidence regarding the stabilizing versus destabilizing role of cryptocurrency derivatives. While Corbet et al. (2018) and Bouteska and Harasheh (2023) highlight increased risk and vulnerability in the Bitcoin market following the expansion of futures trading, Wang et al. (2023) attribute heightened spot price fluctuations to the amplification effects of futures markets. Together, these studies underscore persistent concerns about the effectiveness of Bitcoin futures as hedging instruments in highly volatile environments.

Conversely, another body of research emphasizes the hedging and efficiency-enhancing roles of cryptocurrency futures. Kärkkäinen (2021) characterizes the Bitcoin futures market as a dual-opportunity platform for both hedgers and speculators, noting that Bitcoin miners, in particular, use futures contracts to hedge production risk and stabilize revenues. Hong (2022) similarly argues that the advent of Bitcoin futures improved market stability and informational efficiency by facilitating hedging strategies and lowering barriers to market participation. Examining early trading periods, Sebastião and Godinho (2020) find that CBOE Bitcoin futures share key features with traditional futures contracts, improving price transparency and risk management, although these effects vary across cryptocurrencies.

Extending the analysis over longer horizons, Yu (2022) identifies a dual effect of futures contracts: while they initially introduce additional risk, they gradually evolve into stabilizing instruments that enhance market efficiency and accessibility. This temporal perspective highlights the importance of market maturation in shaping the role of cryptocurrency derivatives.

From a price discovery perspective, Fassas et al. (2019) provide strong evidence that Bitcoin futures play a leading role in incorporating new information into prices, despite higher trading volumes in decentralized spot markets. Their findings also reveal significant bidirectional intraday volatility spillovers between spot and futures markets, emphasizing their integrated dynamics. Augustin et al. (2023) further show that the introduction of BTC–USD futures improved informational efficiency by alleviating arbitrage frictions related to short-sale constraints, block confirmation delays, and market segmentation. These results complement earlier findings by Makarov and

Schoar (2019), who document substantial price dispersion across cryptocurrency exchanges, suggesting that derivatives can mitigate inefficiencies in fragmented markets.

Taken together, the existing literature presents a nuanced and sometimes contradictory view of cryptocurrency futures. While futures contracts can function as effective instruments for risk management and price discovery, their impacts on volatility and market stability vary across time, market conditions, and investor behavior. These mixed findings underscore the need for further empirical research that simultaneously examines long-run equilibrium relationships, short-run dynamics, and time-varying volatility connectedness between spot and futures markets—particularly during periods of market stress and crisis.

Despite the valuable insights offered by prior studies, empirical evidence remains inconclusive regarding the relative dominance of spot and futures markets across short- and long-run horizons, as well as the behavior of their interdependence under crisis conditions. Moreover, much of the existing literature tends to analyze these dimensions in isolation, without integrating long-run equilibrium, short-run adjustment, and volatility dynamics within a unified empirical framework. To address these gaps, the following section introduces an integrated econometric approach that combines VECM-based cointegration analysis with multivariate and asymmetric GARCH models, enabling a comprehensive assessment of spot–futures connectedness under both normal and crisis regimes.

3. Data and Preliminary Analysis

3.1 Data Presentation and Stationarity Test

To investigate the dynamic relationship between Bitcoin spot and futures markets, this study employs a daily dataset obtained from the Standard & Poor's database. The sample consists of 1,863 observations covering the period from December 29, 2017, to February 18, 2025, and includes daily index prices for both Bitcoin spot and Bitcoin futures markets.

Table 1 reports the descriptive statistics for the two series. As cryptocurrency price indices are typically characterized by stochastic trends and potential structural instability, standard unit root testing is required prior to model estimation. Accordingly, the Augmented Dickey–Fuller (ADF) test is conducted with an intercept but without a deterministic time trend, which is a commonly adopted specification for high-frequency financial price series.

The ADF test results indicate that both Bitcoin spot and futures price series are non-stationary in levels but become stationary after first differencing, confirming that both variables are integrated of order one, I(1). This finding justifies the subsequent use of cointegration-based techniques to examine both long-run equilibrium relationships and short-run dynamics between the two markets.

Table 1. Basic Descriptive Statistics of Bitcoin Spot and Futures

	Bitcoin spot	**Bitcoin futures**
Mean	3917.0150	203.9247
Median	3059.0700	159.3600
Maximum	14228.8000	740.7700
Minimum	421.9500	21.7300
Std.Dev.	3194.6820	166.6577
Skewness	1.0497	1.0558
Kurtosis	3.5015	3.5197
Jarque-Bera	361.6655	367.1531

		Bitcoin spot	Bitcoin futures
Probability		0.0000	0.0000
Stationarity (unit root test with constant)	At level	0.9703 (0.1645)	0.9650 (0.0904)
	First difference	0.0001*** (-45.5177)	0.0001*** (-45.5637)

Source: Authors' calculation.
*Note: ***, *, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Values in parentheses correspond to Schwarz Information Criterion–based lag selection for the ADF test.*

3.2 Granger Causality Test

To further explore the short-run informational linkage between Bitcoin spot and futures markets, a Granger causality test is conducted. This test helps identify the direction of predictive influence between the two series prior to estimating more structural models.

Table 2. Results of the Granger Causality Test

Hypothesis	Chi-Square	Probability	Direction of Causality
The Bitcoin Spot market does not Granger-cause the Bitcoin Futures Market	2.3470	0.3093	None
The Bitcoin Futures Market does not Granger-cause the Bitcoin Spot Market	21.2761	0.0000***	Futures → Spot

Source: Author's calculations.
*Note: *** indicates significance at 1% level*

The results reported in Table 2 indicate a unidirectional Granger causality running from the Bitcoin futures market to the Bitcoin spot market in the short term. Specifically, the null hypothesis that futures prices do not Granger-cause spot prices is rejected at the 1% significance level, whereas the reverse hypothesis cannot be rejected. This implies that past information from the futures market contains predictive power for spot price movements, but not vice versa.

This finding is consistent with the price discovery literature, suggesting that futures markets tend to incorporate new information more rapidly, even when futures trading volumes are relatively smaller. The result aligns with Karkkainen (2021), who documents the leading role of Bitcoin futures in price discovery across different frequencies, reinforcing the view that futures markets play a dominant informational role in the short run.

4. Short-Run and Long-Run Dynamics between Bitcoin Spot and Futures Markets

Given that both Bitcoin spot and futures price series are integrated of order one, as established in Section 3, this section proceeds to examine their long-run equilibrium relationship and short-run adjustment dynamics within a cointegration framework. Specifically, a Vector Error Correction Model (VECM) is employed to capture both the long-term cointegrating relationship between the two markets and the short-term responses to deviations from equilibrium. This approach allows for a coherent analysis of price discovery and adjustment mechanisms across spot and futures markets.

4.1 Lag Length Selection and Johansen Cointegration Test

Prior to estimating the VECM, the appropriate lag length for the underlying Vector Autoregression (VAR) model must be determined. Table 3 reports the results of standard lag-order selection criteria, including the Likelihood Ratio (LR), Final Prediction Error (FPE), Akaike Information Criterion (AIC), Schwarz Criterion (SC), and Hannan–Quinn (HQ).

Table 3. Lag Length Selection for the VAR Model

Lag	LR	FPE	AIC	SC	HQ
0	NA	105306.0000	17.2403	17.2463	17.2425
1	570.2375	77720.1900	16.9366	16.9545	16.9432
2	200.0436	70052.1500	16.8327	16.8625	16.8437
3	60.1804	68099.6500	16.8044	16.8462	16.8198
4	38.9247	66966.3200	16.7877	16.8413	16.8074
5	41.4959	65758.5300	16.7695	16.8350*	16.7936
6	23.7287	65197.1400	16.7609	16.8384	16.7894
7	20.6150	64749.1700	16.7540	16.8434	16.7869
8	27.0722*	64077.8700*	16.7436*	16.8449	16.7809*

Source: Authors' calculation.
*Note: * indicates lag order selected by the criterion*

The majority of the information criteria—namely LR, FPE, AIC, and HQ—indicate an optimal lag length of eight. Accordingly, this lag structure is adopted for subsequent cointegration testing and VECM estimation.

With the lag length determined, the Johansen cointegration test is applied to assess whether a long-run equilibrium relationship exists between Bitcoin spot and futures prices. The results of both the trace and maximum eigenvalue tests are reported in Table 4.

Table 4. Johansen Cointegration Test Results

Hypothesis	Trace Statistics	5% Critical Value	Probability**
r=0*	1101.5930	15.4947	0.0000
r≤1	351.1483	3.8414	0.0000
Hypothesis	Max-Eigenvalue Statistics	5% Critical Value	Probability**
r=0*	750.4444	14.2646	0.0000
r≤1	351.1483	3.8414	0.0000

Source: Authors' calculation
Note: Existence of one cointegrating vector at a 5% significance level.
**Indicates the rejection of the null hypothesis at a 5% significance level.*
***Indicates MacKinnon, Haug, and Michelis (1999) p-values.*

Both test statistics reject the null hypothesis of no cointegration at the 5% significance level, confirming the existence of a single cointegrating vector between Bitcoin spot and futures prices. This finding provides strong evidence of a stable long-run equilibrium relationship linking the two markets, justifying the use of a VECM framework.

4.2 Vector Error Correction Model (VECM) Estimation

Given the presence of cointegration between Bitcoin spot and futures prices, a Vector Error Correction Model (VECM) is estimated to jointly capture long-run equilibrium relationships and short-run adjustment dynamics. Alternative specifications are considered with respect to deterministic components in the cointegrating relationship, including the inclusion of a constant and a linear trend.

Model selection is guided by statistical significance and information criteria, as reported in Table 5.

Table 5. VECM Specification Selection

Model specification	t-statistics	AIC
Cointegrating relationship includes a constant	-3.9169	13.2351
Cointegrating relationship includes a constant and trend	-3.8835	13.2353
Cointegrating relationship includes a constant and trend in both long-run and short-run dynamics	-3.7841	13.2356

Source: Authors' calculation.
Note: The reported t-statistics correspond to the error-correction term (ECM). Model selection is based on statistical significance and the Akaike Information Criterion (AIC).

Based on the reported results, the specification including a constant in the cointegrating equation is selected as the preferred model. This specification provides the most appropriate balance between goodness of fit and parsimony and is therefore retained for subsequent analysis. The estimated VECM can be expressed as follows:

$$D(BITCOIN\_INDEX)_t = \alpha_1 + \sum_{i=1}^{p} \beta_{1i} D(BITCOIN\_INDEX)_{t-i} + \sum_{i=1}^{p} \gamma_{1i} D(BITCOIN\_FUTURES\_INDEX)_{t-i} + \psi_1 ECM_{t-1} + \varepsilon_{1t} \quad (1)$$

$$D(BITCOIN\_FUTURES\_INDEX)_t = \alpha_2 + \sum_{i=1}^{p} \beta_{2i} D(BITCOIN\_FUTURES\_INDEX)_{t-i} + \sum_{i=1}^{p} \gamma_{2i} D(BITCOIN\_INDEX)_{t-i} + \psi_2 ECM_{t-1} + \varepsilon_{2t} \quad (2)$$

where ECM_{t-1} denotes the lagged error-correction term derived from the estimated long-run cointegrating relationship.

Table 6. Vector Error Correction Model Estimation Results

Long-term relationship		
$\boldsymbol{Bitcoin\_futures\_index_{t-1}}$		-19.1817 (0.0101) [-1882.6900]
C		-6.9111 (2.6509) [-2.6070]
Error Correction		
	D($Bitcoin\_index$)	D($Bitcoin\_futures\_index$)
CointEq1	-0.9219 (0.2353) [-3.9169]	-0.0312 (0.0125) [-2.4829]

Source: Authors' calculation.
Note: The table reports estimates from the Vector Error Correction Model (VECM). Standard errors are reported in parentheses, and t-statistics are reported in square brackets. CointEq1 denotes the error-correction term derived from the cointegrating relationship.

The VECM estimation results confirm the existence of a stable long-run equilibrium relationship between Bitcoin spot and futures prices, indicating that the two markets are closely linked over time. The error-correction coefficients are negative and statistically significant in both equations, confirming convergence toward the long-run equilibrium following short-term deviations.

Importantly, the magnitude of the error-correction coefficient differs substantially across markets. The adjustment coefficient in the Bitcoin spot equation is relatively large in absolute value and statistically significant, implying that deviations from the long-run equilibrium are primarily corrected through adjustments in the spot market. This finding suggests that Bitcoin spot prices respond more strongly and rapidly to disequilibria, restoring the long-term relationship when shocks occur. This behavior is consistent with the results reported by Özdemir (2021).

In contrast, the adjustment coefficient in the futures equation is smaller in magnitude, though still negative and statistically significant, indicating a weaker and slower response to disequilibria. This asymmetric adjustment pattern implies that while both markets participate in restoring equilibrium, the futures market plays a more limited role in the correction process. These results support the view that Bitcoin futures contracts contribute primarily to information transmission and price discovery, rather than serving as the main channel for equilibrium adjustment.

Accordingly, the findings suggest a complementary market structure in which the futures market plays a dominant informational role, while the spot market acts as the primary adjustment mechanism. This interpretation is consistent with Frino et al. (2025) and Kapar and Olmo (2019), who argue that futures markets typically lead spot markets in the price discovery process.

At this stage of the analysis, the results also support the view that futures markets contribute to stabilizing the spot market and enhancing its informational efficiency. This outcome aligns with Shynkevich (2021), who attributes the stabilizing effect of Bitcoin futures to their ability to facilitate faster incorporation of information. Similarly, Kim et al. (2020) document that although Bitcoin became more volatile immediately following the introduction of futures contracts, volatility declined over time as the market matured.

Short-run dynamics, however, display a different pattern. The spot market absorbs the majority of short-term adjustments required to restore equilibrium, reflecting its higher liquidity and greater responsiveness to new information. By contrast, the futures market influences short-term dynamics but adjusts more gradually to deviations from the long-run relationship. This asymmetric behavior underscores the distinct but interconnected roles played by spot and futures markets in the Bitcoin price formation process.

4.3 Impulse Response Function

To further examine the dynamic transmission of shocks between Bitcoin spot and futures markets, impulse response functions (IRFs) are estimated based on the VECM framework, as illustrated in Figure 1.

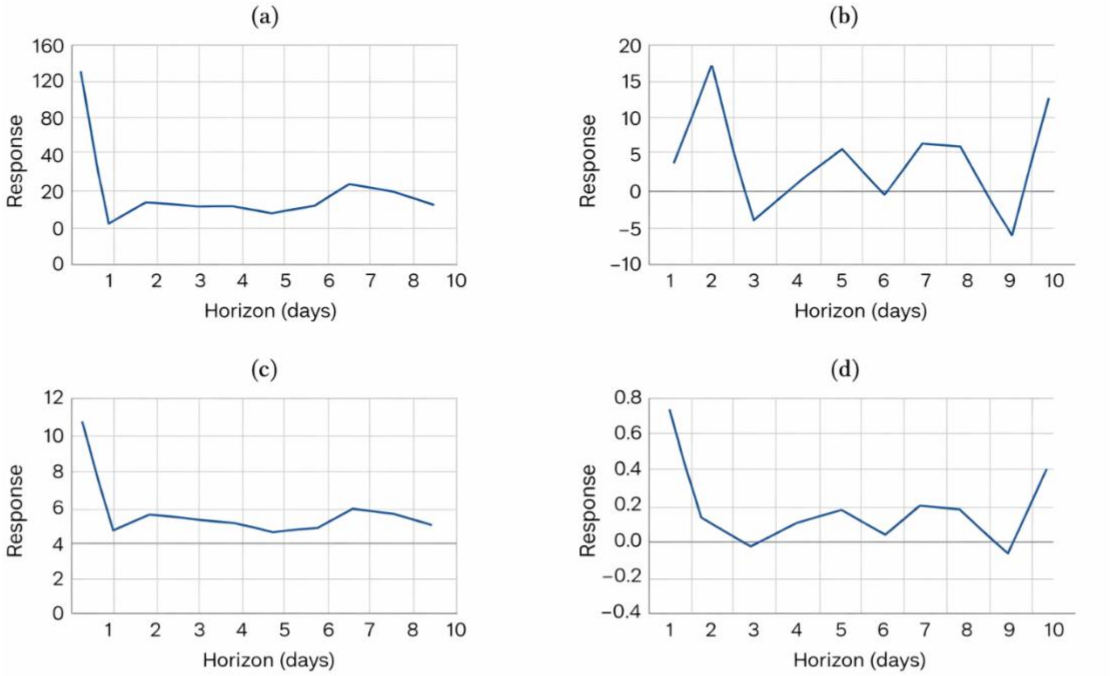

Figure 1. Impulse Response Functions (IRF)
Source: Authors' calculation.
Note: The horizontal axis denotes the response horizon (days), while the vertical axis reports the impulse responses of Bitcoin spot and futures returns to one-standard-deviation shocks based on the VECM estimation. Panels (a)–(d) illustrate the responses of each market to shocks originating from itself and from the other market.

The results reveal an asymmetric dynamic relationship between the Bitcoin spot and futures markets. The spot market exhibits an immediate and pronounced response to its own shocks, followed by a rapid return to equilibrium, reflecting its high liquidity and informational efficiency. This behavior is consistent with the findings of Baur and Dimpfl (2018). By contrast, responses involving the futures market appear more gradual, indicating slower adjustment dynamics.

Overall, the IRF analysis corroborates the VECM results by illustrating that short-run shock absorption is primarily driven by the spot market, while futures markets play a complementary role in transmitting information across markets.

5. Dynamic Relationship Exploration and Crisis Effect Estimation

5.1 Modeling Process

Shifting attention to the joint dynamics of cryptocurrency prices and their sensitivity to crisis episodes, this section adopts a two-step econometric approach to capture both time-varying interdependence and asymmetric volatility effects between Bitcoin spot and futures markets.

In the first stage, a multivariate GARCH framework—specifically a BEKK-GARCH(2,1) model—is employed to model the dynamic variance–covariance structure of spot and futures returns. This specification allows for direct spillover effects and captures the evolution of market co-movements over time. The conditional mean equation is specified as:The conditional mean equation is:

$$r_t = C + \varepsilon_t, \varepsilon_t \mid \mathcal{F}_{t-1} \sim (0, H_t) \quad (3)$$

where r_t denotes the vector of spot and futures returns, and H_t represents the conditional variance–covariance matrix.

The conditional variance–covariance matrix follows the BEKK representation:

$$H_t = M'M + \sum_{i=1}^{2} A_i' \varepsilon_{t-i}\varepsilon_{t-i}' A_i + B_1' H_{t-1} B_1 \quad (4)$$

Based on the estimated H_t, the dynamic conditional correlation between Bitcoin spot and futures returns at time t is computed as:

$$\rho_{ij,t} = \frac{h_{ij,t}}{\sqrt{h_{ii,t}h_{jj,t}}} \quad (5)$$

In the second stage, the extracted dynamic conditional correlations are treated as a time-varying series to analyze their volatility behavior and crisis sensitivity. To account for potential asymmetries—where negative shocks may exert stronger effects than positive ones—a GJR-GARCH(1,1) model is employed.

The mean equation for the dynamic correlation is specified as:

$$\rho_t = C + \delta_1 \text{COVID}_t + \delta_2 \text{SVC}_t + \varepsilon_t \quad (6)$$

where $COVID_t$ and SVC_t are dummy variables capturing crisis periods. The COVID-19 period follows Amamou and Bargaoui (2022) and spans from February 1 to March 24, 2020, corresponding to the initial phase of the pandemic characterized by border closures, lockdowns, and heightened systemic risk. The Silicon Valley crisis dummy covers the period from March 8 to March 13, 2023, beginning with the announcement of large-scale securities losses and ending with the Federal Reserve's intervention to stabilize the financial system.

The error term satisfies:

$$\varepsilon_t \mid \mathcal{F}_{t-1} \sim (0, h_t)$$

The conditional variance equation is defined as:

$$h_t = \omega + \alpha\varepsilon_{t-1}^2 + \gamma\varepsilon_{t-1}^2 \mathbb{I}(\varepsilon_{t-1} < 0) + \beta h_{t-1} \quad (7)$$

where α captures the ARCH effect $(\text{short} - \text{run shock sensitivity})$, γ measures asymmetric (leverage) effects, and β represents volatility persistence. The persistence condition is given by $\alpha + \beta + \frac{1}{2}\gamma < 1$

Overall, this two-step framework enables a comprehensive examination of volatility transmission, asymmetric responses, and crisis-driven dynamics, thereby offering deeper insights into spot–futures interdependence under normal and stressed market conditions.

5.2 Results and Discussion

Table 6 reports the estimation results of the two-step BEKK-GARCH and GJR-GARCH framework, providing insights into the dynamic interdependence, volatility transmission, and crisis sensitivity between Bitcoin spot and futures markets.

Table 6. Two-Step BEKK-GARCH and GJR-GARCH Results for Bitcoin Spot–Futures Dynamics

First step: The BEKK-GARCH(2,1) Estimation Results:			
Mean Equation			
		Coefficient	p-value
$\boldsymbol{C_1}$(Bitcoin spot)		−3.2343	0.0021 ***
$\boldsymbol{C_2}$(Bitcoin futures)		−0.1780	0.0028 ***
Variance-Covariance Equation			
		Coefficient	p-value
Constant (M)	M_{11}	72.2305	0.0000 ***
	M_{12}	3.9995	0.0000 ***
	M_{22}	0.2216	0.0000 ***
ARCH effects (A_1)	$A_{1,11}$	0.3250	0.0000 ***
	$A_{1,22}$	0.3395	0.0000 ***
ARCH effects (A_2)	$A_{2,11}$	0.0625	0.0000 ***
	$A_{2,22}$	0.0184	0.2085
GARCH effects (B_1)	$B_{1,11}$	0.9439	0.0000 ***
	$B_{1,22}$	0.9406	0.0 ***
Second Step: The GJR-GARCH(1,1) Estimation Results:			
Mean Equation			
	Coefficient	p-value	
C	0.9852	0.0000***	
COVID-19 Crisis	-0.0184	0.0000***	
Silicon-Valley Crisis	0.0004	0.9726	
Variance Equation			
	Coefficient	p-value	
C	9.20E-05	0.0000***	
$\boldsymbol{\alpha}$	0.4163	0.0001***	
$\boldsymbol{\gamma}$	0.4389	0.0001***	
$\boldsymbol{\beta}$	0.1243	0.0000***	
Persistence ($\alpha+\beta+0.5\boldsymbol{\gamma}$)		0.7602	

***, **, * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Source: Authors' calculation

*Note: This table presents two-step BEKK-GARCH(2,1) and GJR-GARCH(1,1) estimation results for Bitcoin spot–futures dynamics. COVID-19 and SVC are crisis dummy variables. Persistence is defined as $\alpha+\beta+0.5\gamma$. ***, **, and * denote significance at the 1%, 5%, and 10% levels.*

5.2.1 Dynamic Interdependence and Volatility Spillovers

The first-stage BEKK-GARCH(2,1) results reveal strong and statistically significant ARCH effects for both spot and futures returns, indicating that volatility in each market responds immediately to past shocks originating from itself and from the other market. This finding provides clear evidence of short-term volatility spillovers and confirms the existence of a tightly interconnected spot–futures structure in the Bitcoin market.

Moreover, the estimated GARCH coefficients are large and highly significant, suggesting a high degree of volatility persistence in both markets. Once a shock occurs—whether in the spot or futures segment—its impact on conditional volatility tends to persist over time. This result implies that the Bitcoin market exhibits strong memory effects, whereby past shocks continue to influence current market uncertainty. Such persistence is consistent with Enow (2024), who documents long-term memory characteristics in financial markets, and aligns with earlier findings on cryptocurrency volatility clustering.

Taken together, the BEKK-GARCH results demonstrate that Bitcoin spot and futures markets are not only contemporaneously linked but also dynamically interdependent, with shocks transmitting rapidly and persistently across markets. These findings complement the earlier VECM and impulse response results (Sections 4.2 and 4.3), which highlighted long-run equilibrium relationships and asymmetric short-run adjustments. While the VECM captures mean dynamics and price discovery roles, the GARCH-based analysis reveals that volatility transmission constitutes an additional and important channel of market connectedness.

5.2.2 Crisis Effects and Asymmetric Volatility Dynamics

The second-stage GJR-GARCH(1,1) estimation focuses on the volatility of the dynamic conditional correlation and explicitly accounts for crisis episodes. The results indicate that the ARCH (α), GARCH (β), and asymmetry (γ) coefficients are all positive and statistically significant, confirming the presence of asymmetric volatility behavior. Negative shocks exert a stronger impact on future correlation volatility than positive shocks of the same magnitude, validating the leverage-effect mechanism in spot–futures interdependence.

The persistence measure, calculated as $\alpha+\beta+0.5\gamma\alpha+\beta+0.5\gamma$, remains below unity, indicating a stable but highly persistent correlation volatility process. This suggests that although shocks gradually dissipate, their influence on market co-movement can be substantial and long-lasting.

Regarding crisis effects, the COVID-19 dummy variable exhibits a statistically significant and negative coefficient, implying that the pandemic reduced the dynamic correlation between Bitcoin spot and futures markets. This result reflects heightened uncertainty and structural disruption during the early phase of the pandemic, when market participants adjusted trading behavior amid extreme macro-financial stress. The finding supports the view that crisis periods can temporarily alter the transmission mechanisms between spot and derivatives markets, amplifying volatility while weakening traditional co-movement patterns.

In contrast, the Silicon Valley Bank (SVB) crisis dummy is statistically insignificant, indicating that this episode did not materially affect the dynamic correlation between Bitcoin spot and futures prices. This outcome is consistent with Wang et al. (2024), who document the resilience of cryptocurrency markets following the SVB collapse, despite elevated uncertainty in traditional financial systems. The result suggests that not all crisis events exert symmetric or uniform effects on crypto-market dynamics, and that market-specific characteristics play a crucial moderating role.

5.2.3 Synthesis and Implications

Overall, the results from the two-step BEKK-GARCH and GJR-GARCH framework confirm that Bitcoin spot and futures markets are characterized by strong dynamic interdependence, persistent volatility spillovers, and asymmetric responses to negative shocks. Crisis episodes—particularly systemic shocks such as COVID-19—can significantly reshape these dynamics, whereas more localized financial disturbances may exert limited influence.

By jointly examining long-run equilibrium (VECM), short-run adjustment (IRF), and time-varying volatility connectedness (GARCH), this study provides a comprehensive depiction of spot–futures interactions across normal and stressed market conditions. These findings underscore the importance of considering both price-level dynamics and volatility transmission when assessing the role of cryptocurrency derivatives in market stability and risk propagation, thereby setting the stage for the policy discussion in the following section.

6. Conclusion

This study provides empirical evidence of a significant long-run relationship between Bitcoin spot and futures markets. Cointegration tests and VECM estimates confirm the existence of a stable equilibrium, accompanied by meaningful short-run adjustments. The error-correction terms are statistically significant, and Granger causality results indicate that the futures market tends to lead the spot market, particularly during periods of heightened financial stress.

These findings underscore the role of the futures market in price discovery under conditions of increased uncertainty, while the spot market functions as the primary mechanism for correcting deviations from long-run equilibrium. The observed dual behavior suggests that the futures market is informationally efficient in the short run, whereas the spot market plays a more dominant role in long-run adjustments. The absence of persistent shock effects further indicates that both markets absorb information relatively quickly, although the spot market remains the main adjustment channel, likely reflecting its higher liquidity and responsiveness to new information.

Beyond equilibrium dynamics, the analysis highlights the highly dynamic nature of Bitcoin markets and their sensitivity to crisis environments. Using a robust volatility framework based on BEKK-GARCH and GJR-GARCH models, the study reveals strong interdependence between spot and futures markets, characterized by significant bidirectional volatility spillovers and high conditional correlations. The results also indicate asymmetric volatility behavior, with negative shocks exerting a stronger and more persistent impact on future volatility than positive shocks, consistent with the leverage effect documented in recent studies.

Importantly, the findings point to the presence of market synergies that vary across both short- and long-run horizons and intensify during crisis episodes. This pattern aligns with existing evidence that cryptocurrency markets are increasingly exposed to systemic shocks and contagion effects, rather than operating as isolated financial segments. The observed amplification of co-movements during periods of stress further confirms that futures markets play a central role in facilitating price discovery while simultaneously transmitting risk across market segments.

By jointly modeling long-run equilibrium relationships, short-run dynamics, and time-varying volatility, this study offers a comprehensive view of spot–futures interactions in the Bitcoin market. The results contribute to a deeper understanding of arbitrage, hedging, and speculative mechanisms that arise from the coexistence of spot and derivative markets, and highlight the critical role of Bitcoin futures as indicators of underlying market risks in an increasingly interconnected and volatile financial environment

7. Policy Implications

The findings of this study carry several important policy implications for regulators and market participants concerned with the stability and efficiency of cryptocurrency markets. First, the dominant role of Bitcoin futures in price discovery suggests that derivatives markets serve as a critical channel for information transmission. Regulators should therefore pay close attention to the functioning, transparency, and liquidity of futures markets, particularly during periods of heightened volatility.

Second, the strong volatility persistence and asymmetric spillover effects imply that negative shocks can have prolonged destabilizing impacts across spot and futures markets. This underscores the importance of monitoring systemic risk indicators and developing early-warning systems that integrate information from both segments of the cryptocurrency market. Enhanced disclosure requirements and real-time surveillance mechanisms could help mitigate the amplification of adverse shocks.

Third, the state-dependent nature of market connectedness highlights the limitations of uniform regulatory approaches. During crisis periods, policy interventions may need to focus on stabilizing expectations, improving market transparency, and preventing excessive speculative behavior that could exacerbate volatility transmission. In more stable periods, regulatory efforts can emphasize market development, risk management practices, and the orderly integration of derivative instruments.

More broadly, the analytical framework and empirical insights developed in this study are relevant not only for Bitcoin but also for other digital assets and emerging financial markets. As cryptocurrency derivatives continue to expand globally, particularly in emerging economies, adopting adaptive, state-contingent regulatory strategies will be essential to harness the benefits of innovation while safeguarding market stability.

8. References

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