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Filtering amplitude dependence of correlation dynamics in the cryptocurrency market

Cryptocurrencies, Fluctuations, Cross-correlations, Complex Networks, Minimal Spanning Trees

Extended Abstract

Financial markets are widely regarded as among the most complex systems in the world, shaped by vast networks of interconnections and variables that determine their structure and dynamics [1]. A more recent development within these markets is the rise of cryptocurrencies. Since the launch of Bitcoin in 2009, the cryptocurrency sector has expanded rapidly, evolving from a niche interest into a significant component of the global financial system [2].

The study of complex systems often relies on multivariate time series, from which correlation matrices are constructed. These matrices can be expressed as networks and further simplified into a minimum spanning tree (MST). However, standard coefficients inherently compress the data, discarding much of the information present in the original time series. This reduction largely arises because such coefficients average correlations across the full range of fluctuations, without accounting for potential variations in correlation strength at different fluctuation amplitudes.

This research investigates the dynamic correlation structure of the cryptocurrency market by applying the q-dependent detrended cross-correlation coefficient $\rho(q,s)$ [3] and the associated q-dependent minimum spanning trees qMST [4]. Unlike classical correlation analysis, this methodology enables a fluctuation-selective view of inter-asset dependencies, allowing us to distinguish how ordinary and extreme price changes organize the market differently. We use minute-by-minute price data for 140 cryptocurrencies traded on Binance between January 2021 and September 2024, a period encompassing the 2021 bull run, the Terra/Luna collapse in 2022, and the volatile conditions of 2023–2024. A rolling-window approach (7 days, shifted daily) was employed to track temporal evolution. For each window, correlation matrices $\rho(q,s)$ were calculated, transformed into distance matrices, and filtered into qMSTs. Spectral characteristics (largest eigenvalue λ_1, eigenvector contributions) and network measures (node degree, average path length) were used to monitor changes, while a regression-based procedure allowed filtering out the dominant market mode to examine residual dependencies.

The results show that until April 2022 the correlation network for $q = 1$ (typical fluctuations) was strongly centralized around Bitcoin (BTC), reflected in high λ_1 and short path lengths. The Terra/Luna crash marked a structural break: correlations weakened, λ_1 dropped, and the qMST decentralized, with Ethereum (ETH) and other altcoins (ADA, DOT, LINK, MANA, SAND, VET) gaining prominence. This shift indicates a transition toward a more diversified, multi-central market structure. Comparing fluctuation amplitudes, we find that correlations for moderate price changes ($q = 1$) are stronger and more stable, producing cohesive networks dominated first by BTC and later by several hubs. For large fluctuations ($q = 4$), correlations are generally weaker and qMSTs appear dispersed, with no clear hub. However, during crash periods, $\lambda_1(q = 4)$ spikes and qMSTs collapse into fully decentralized “all-fall-together” states, indicating that diversification fails during market panics. After filtering out the market factor λ_1, overall correlations weaken further, networks lose hierarchy, and transient hubs (e.g.,

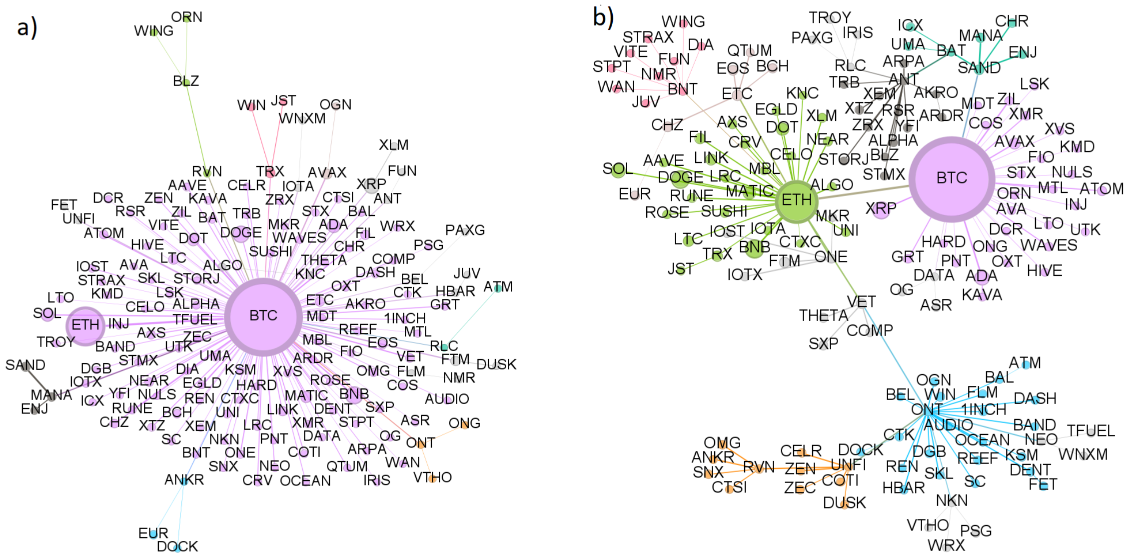

Figure 1: Example qMSTs ($q = 1, s = 10$) before and after the Terra/Luna crash a) 22-Apr-2022, b) 18-May-2022. Node size is proportional to the average volume in the analyzed period, while edge thickness reflects the strength of the correlation. Potential communities are marked by colors.

SAND in 2024) disappear, while BTC and ETH retain persistent centrality—demonstrating that their structural role is not solely due to common trends.

These findings highlight two key points. First, the cryptocurrency market underwent a major reorganization in 2022, moving away from BTC's monopoly toward a more distributed network, consistent with market maturation. Second, correlation structures depend strongly on the fluctuation regime: cohesive and hub-like for typical changes, dispersed and fragile for extremes. The qMST framework thus provides a tool for tracking regime shifts, assessing systemic risk, and understanding the limits of diversification. This may introduce novel elements for traditional correlation-based portfolio construction methods by tailoring allocation, hedging, and risk management strategies to fluctuation-specific correlation patterns. While demonstrated here for cryptocurrencies, the methodology can be applied to other financial, biological, or social complex systems where dependencies evolve with fluctuation amplitude.

References

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