



Munich Personal RePEc Archive

# **Uncertainty and Risk in Cryptocurrency Markets: Evidence of Time-frequency Connectedness**

rao, amar and Dagar, Vishal and dagher, leila and Shobande,  
Olatunji

2024

Online at <https://mpra.ub.uni-muenchen.de/120582/>  
MPRA Paper No. 120582, posted 06 Apr 2024 14:19 UTC

# Uncertainty and Risk in Cryptocurrency Markets: Evidence of Time-frequency Connectedness

Amar Rao, Vishal Dagar, Leila Dagher, and Olatunji A. Shobande

## Abstract

This study aims to investigate the spillover effects from geopolitical risks (proxied by the geopolitical risk index) and cryptocurrencies-related uncertainty (proxied by the Cryptocurrency Uncertainty Index) to cryptocurrencies. We utilize the Baruník and Křehlík (2018) framework to detect time-frequency connectedness. Our investigation for the period 2017 to 2022 discovers significant spillover effects from both indices to cryptocurrencies. Utilizing the information transmission theory and network graphs, our findings reveal that some cryptocurrencies function as net receivers of spillovers from geopolitical risks and uncertainty in the short-term, while over longer time horizons they transform into net transmitters of spillovers to uncertainty. The study contributes to better understanding how uncertainty due to various factors (geopolitical, policy changes, regulatory changes, etc.) could affect the cryptocurrencies' markets.

**Keywords:** cryptocurrencies; geopolitical risk; market uncertainty; time–frequency connectedness

**JEL Classification:** C58, G15

## 1. Introduction

Cryptocurrencies have undergone a dramatic transformation in recent years. Currently, the cryptocurrency market has a total capitalization of approximately US\$ 0.948 trillion. However, Bitcoin (BTC) alone had a market capitalization of US\$ 1.28 trillion in November 2021, despite experiencing many bubbles and crashes throughout its history (Thampanya et al., 2020). Bitcoin experienced a dramatic surge from US\$ 1,000 to nearly US\$ 20,000 in late 2017, plummeting back down to US\$ 3,000 in 2019. Regulatory crackdowns have had a notable impact on cryptocurrencies' value in many countries, especially China. In 2015, Ethereum (ETH) enabled blockchain technology in smart contracts and sparked the Initial Coin Offer (ICO) boom. More recently, the rise of decentralized finance (DeFi) and decentralized exchanges (DEX) have reshaped the cryptocurrency landscape. Cryptocurrencies now exhibit similar characteristics to those of developed financial markets, such as currency markets (Drożdż et al., 2018).

Recent research has examined the safe haven properties of cryptocurrencies, particularly during the COVID-19 pandemic (Dasauki & Kwarbai, 2021; Kakinuma, 2023; Maitra et al., 2022). Several studies provide evidence that Bitcoin displays safe haven properties comparable to those of gold (Bouri et al., 2020; Shahzad et al., 2019, 2020; Thampanya et al., 2020). In contrast, other studies have found that cryptocurrency markets are highly correlated with equity markets during market downturns (Yarovaya et al., 2022). Thus, the role of cryptocurrencies as a hedge for financial investments remains a topic of hot debate, with uncertainty surrounding their effectiveness.

Our research is grounded in information transmission theory, which emphasizes the importance of information in shaping the expectations of investors, traders, and policymakers and influencing the supply and demand equilibrium. In today's digital age, investors have access to a wide range of information channels, including social media, online blogs, and internet news, that can rapidly disseminate information and affect their beliefs and trading decisions. Models based on rational disagreements, such as those developed by He and Wang (1995) and Tetlock (2010), suggest that public information can lead to trade only when it helps resolve information asymmetry and results in traders' beliefs converging (Tetlock, 2014). These models provide a helpful theoretical framework for understanding how the transmission of information can impact financial markets and serve as a basis for our investigation into the relationship between information transmission and market outcomes.

The efficient functioning of financial markets, which encompasses the determination of prices and asset allocations, relies on the intricate interplay between two fundamental factors: the demand for securities by investors and the willingness of companies to supply these securities. Within the realm of finance, information transmission emerges as a pivotal and central player due to its inherent capacity to shape the expectations held by both investors and managers regarding future developments. It is this very influence that subsequently exerts a profound and far-reaching impact on the delicate equilibrium between supply and demand within these markets. Numerous scholarly endeavors have been dedicated to the exploration of information transmission, with a primary focus on the meticulous examination of stock market dynamics in response to a myriad of corporate events. These events span a wide spectrum, encompassing everything from the disclosure of earnings announcements to the dissemination of analyst forecasts. A noteworthy instance that comes to the fore is the seminal work of Fama et al. (1969), which conducted an event study that meticulously examined the trajectory of stock prices for firms following the public revelation of stock splits.

In the realm of the cryptocurrency market, characterized by its rapid pace and the continuous influx of information, these dynamics are no less relevant. Earlier studies have utilized information transmission as a theoretical basis to comprehend the intricate workings of cryptocurrencies (e.g., Akyildirim et al., 2021; Bação et al., 2018; Ji et al., 2019; Koutmos, 2018). In alignment with this existing body of research, our aim was to delve into the theory of information transmission to gain a deeper understanding of how external factors, such as geopolitical risks and regulatory uncertainties, can exert their influence on the conduct of market participants, including both investors and policymakers. At the core of this discussion lies the recognition that information stands as a fundamental driver of market behavior within the cryptocurrency space. This encompasses a dual nature of information, encompassing both the public information domain, consisting of news reports, social media posts, and official announcements, and the realm of private information, which may be confidentially held by individual investors and insiders within the market. It is through the transmission of information that profound ripple effects are generated, directly impacting market sentiment, liquidity, and the valuation of cryptocurrency assets.

Geopolitical frictions, tensions, and events such as elections can create fluctuations or uncertainties in political environments, which can significantly impact the prices of financial assets. Balcilar et al. (2018) asserted that geopolitical risk is a crucial determinant of investment decisions, as it can alter business cycles, financial markets, and economic trajectories. The risk emanating from geopolitical tensions causes investors to reassess their portfolios taking into account the stability of government policies. For example, the recent disagreement between USA and China over the disputed island in the South China Sea had a significant indirect impact on business sentiments. Increased geopolitical risks increase asset volatility (Al Mamun

et al., 2020). As a result many studies have employed the geopolitical risk index (GPRD) as a proxy for adverse geopolitical events and associated risks (Caldara and Iacoviello, 2022).

Lucey et al. (2022) introduced a new index, the Cryptocurrency Uncertainty Index (UCRY), which captures two primary types of uncertainty: Cryptocurrency Policy Uncertainty (UCRY Policy) and Cryptocurrency Price Uncertainty (UCRY Price). This index can help assess how policy and regulatory debates influence the returns and volatility of cryptocurrencies. Studies by Al-Shboul et al. (2022), Elsayed et al. (2022), Haq and Bouri (2022) have used the UCRY to understand the dynamic connection with cryptocurrencies, equities, and gold and have established strong evidence of their connectedness.

Our research aims to investigate spillover effects from the GPRD and the UCRY to cryptocurrencies. We utilize network graphs from the frequency connectedness framework developed by Baruník and Křehlík (2018) to accomplish this goal. We aim to answer the following two research questions:

RQ 1: Does the magnitude of spillovers from the UCRY exceed those from the GPRD?

RQ 2: Are there any differences in the magnitude of the spillovers caused by UCRY and GPRD in the short, medium, and long terms?

Prior research has explored the impact of different uncertainties on cryptocurrencies, focusing on individual assets or groups of assets. For instance, Raza et al. (2023) examined the effect of financial regulatory policy uncertainty on a portfolio of six cryptocurrencies using a GARCH-MIDAS framework, finding that higher uncertainty was associated with lower volatility. Khalfaoui et al. (2023) employed a quantile cross-spectral analysis and Google Trends data to investigate the impact of the Russia-Ukraine war on cryptocurrencies. Their research revealed that investors responded to the conflict by demanding liquidity, with a resulting decline in cryptocurrency prices. Al-Shboul et al. (2023) find a negative effect of economic policy uncertainty on the total spillover among all currencies (traditional and cryptocurrencies) at all quantiles. In other words, the higher the uncertainty level, the lower the level of connectedness among currencies. Tong et al. (2022) quantified the impact of attention from the search engine (Google Trends) and social media attention (Twitter) and documented bi-directional causality between these attentions and cryptocurrencies. Sawarn and Dash (2023), using a time frequency-based connectedness, concluded that US financial stress transmits uncertainty to cryptocurrencies on a net basis. Long et al. (2022) investigated the cross-sectional impact of geopolitical risk on the returns of 2000 cryptocurrencies, establishing that cryptos with higher geopolitical betas tend to underperform those with the lowest betas. Akyildirim et al. (2021) study the dynamic network connectedness between cryptocurrency returns and investor sentiments and find that information transmission is from cryptocurrency returns towards sentiments.

The remainder of the paper is structured as follows. Section 2 provides a description of the data and the methodology, while section 3 summarizes the results and offers insights about the findings. Finally, section 4 concludes with some remarks.

## **2. Data and methodology**

### **2.1. Data description**

We use weekly data for nine major cryptocurrencies (Bitcoin, Ethereum, Basic Attention Token, Bitcoin Cash, Binance Coin, Dogecoin, Litecoin, OmiseGO, and Stellar Lumens) and two uncertainty indices, Geo-political Risk Index (GPRD)<sup>1</sup> and Cryptocurrency Uncertainty Index (UCYR Policy), for the period spanning November 5, 2017 to 25 December 25, 2022. We source the data of cryptocurrencies from the website of coinmarketcap.com and GPRD and UCRY data from their official websites. Table 1 provides more details about the variables and notations used, and figure 1 displays the time plots of the nine cryptocurrencies.<sup>2</sup> We calculate weekly percentage change using the formula:  $\%Change = \ln\left(\frac{P_t}{P_{t-1}}\right)$ ; where  $P_t$  denotes the contemporaneous weekly price while  $P_{t-1}$  denotes the previous week's price.

**Table 1. Definition of Variables**

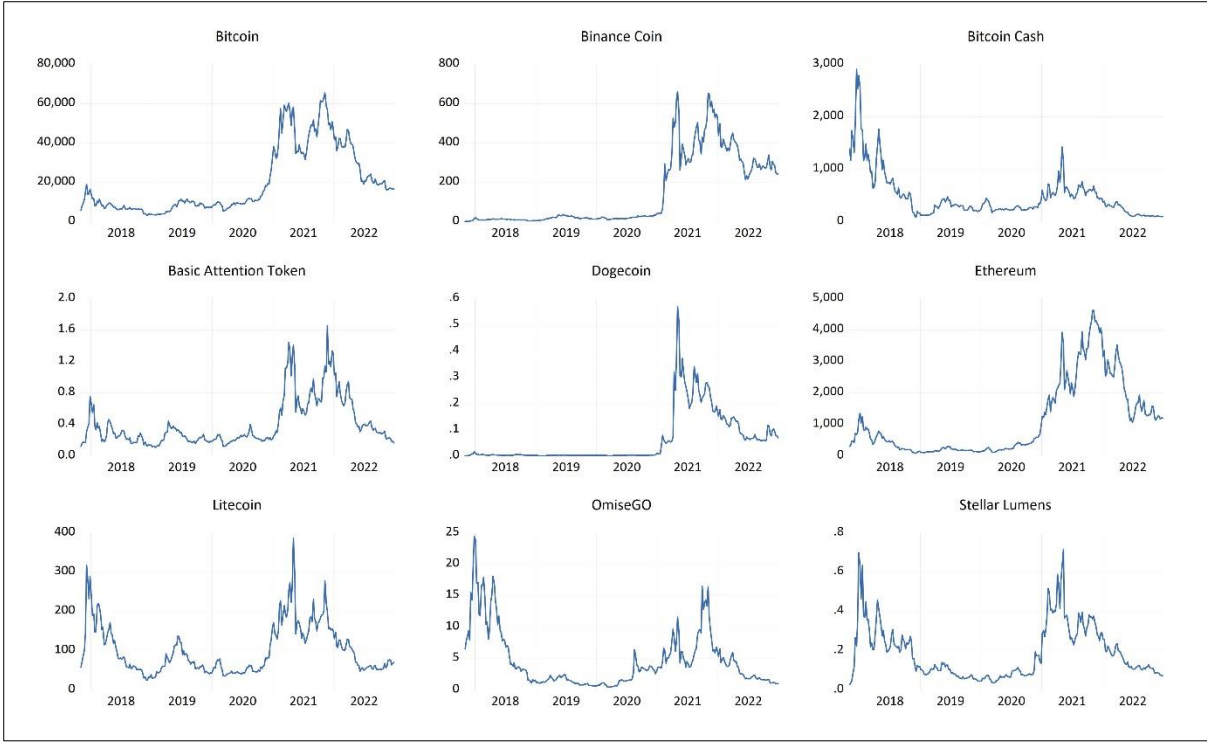
<b>Variable</b>	<b>Label</b>	<b>Frequency</b>
Geopolitical Risk Index	GPRD	Weekly*
Cryptocurrency Uncertainty Index	UCRY	Weekly
Bitcoin	BTC	Weekly
Ethereum	ETH	Weekly
Basic Attention Token	BAT	Weekly
Bitcoin Cash	BCH	Weekly
Binance Coin	BNB	Weekly
Dogecoin	DOGE	Weekly
Litecoin	LTC	Weekly
OmiseGO	OMG	Weekly
Stellar Lumens	XLM	Weekly

Note: \* GPRD index was converted from daily to weekly frequency by using averages.

---

<sup>1</sup> Geopolitical risk, as defined by Caldara and Iacoviello (2022), pertains to the potential for, occurrence of, and intensification of adverse events linked to wars, terrorism, and any strains among nations and political entities, which disrupt the peaceful progression of international relations. (<https://www.matteoiacoviello.com/gpr.htm>)

<sup>2</sup> Descriptive statistics for the variables and diagnostic test results are found in the Appendix.



**Figure 1. Weekly Closing Prices of Cryptocurrencies**

## 2.2. Methodology

Baruník and Křehlík (2018) proposed a frequency connectedness method to measure the directional connectedness between two sets of variables in a frequency domain. Let us denote the two variable sets as  $X$  and  $Y$ . The frequency connectedness measure is defined as:

$$FC_{X \rightarrow Y}(\omega) = \sum_{j=1}^{p_Y} \frac{\left| \sum_{i=1}^{p_X} \gamma_{XY,ij}(\omega) \right|}{\left| \sum_{i=1}^{p_X} \gamma_{XX,ii}(\omega) \right|} \quad (1)$$

Where  $\gamma_{XX,ii}(\omega)$  is the auto-covariance of the  $i$ -th variable in set  $X$ ,  $\gamma_{XY,ij}(\omega)$  is the cross-covariance between the  $i$ -th variable in set  $X$  and  $j$ -th variable in set  $Y$ , and  $\omega$  is the frequency.

The measure  $FC_{X \rightarrow Y}(\omega)$  represents the proportion of the variation in set  $Y$  that can be explained by setting at frequency  $\omega$ , after controlling for the variation within set  $Y$  at the same frequency. The measure ranges between 0 and 1, where 0 indicates no connectedness, and 1 indicates complete connectedness.

To measure the total frequency connectedness from set  $X$  to set  $Y$ , the measure is integrated across all frequencies:

$$FC_{X \rightarrow Y} = \int_{-\pi}^{\pi} FC_{X \rightarrow Y}(\omega) d \quad (2)$$

Similarly, the frequency connectedness from set  $Y$  to set  $X$  can be defined as:

$$FC_{Y \rightarrow X}(\omega) = \sum_{i=1}^{p_X} \left| \frac{\sum_{j=1}^{p_Y} \gamma_{YX,ji}(\omega)}{\sum_{j=1}^{p_Y} \gamma_{YY,jj}(\omega)} \right| \quad (3)$$

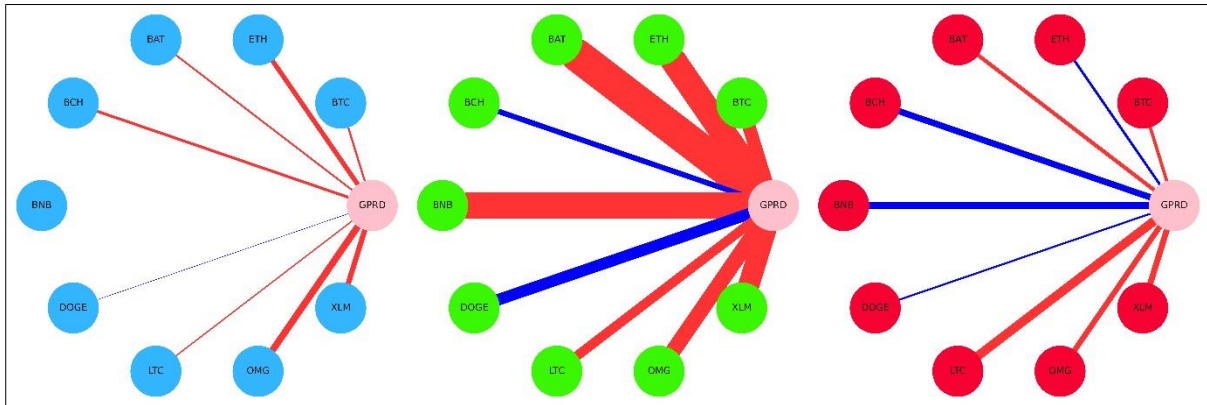
And the total frequency connectedness from set Y to set X is derived as:

$$FC_{Y \rightarrow X} = \int_{-\pi}^{\pi} FC_{Y \rightarrow X}(\omega) d \quad (4)$$

### 3. Empirical results

Figure 2 displays the spillovers between GPRD and the selected set of cryptocurrencies.<sup>3</sup> The 1st, 2nd, and 3rd sub-figures (left to right) in figure 2 refer to (1 week), frequency 2 (1 to 4 weeks), and frequency 3 (4 weeks to infinity), respectively. GPRD is a net transmitter of spillovers to DOGE for all three frequency bands, indicating that changes in GPRD are causing spillover effects that are impacting the price and market dynamics of DOGE. This finding suggests that DOGE is highly sensitive to policy and regulatory risk changes.

Moreover, for frequency 3, BNB, BCH, and ETH are net receivers of spillovers from GPRD, suggesting that changes in GPRD are causing spillover effects impacting these cryptocurrencies' price and market dynamics. The fact that these cryptocurrencies are net receivers of spillovers from GPRD for the long-term frequency band indicates that they may be more sensitive to policy and regulatory risk over a longer time horizon. Overall, these results suggest spillover effects from changes in policy and regulatory risk, as captured by GPRD, to the selected set of cryptocurrencies and that these spillover effects can occur over different time horizons.



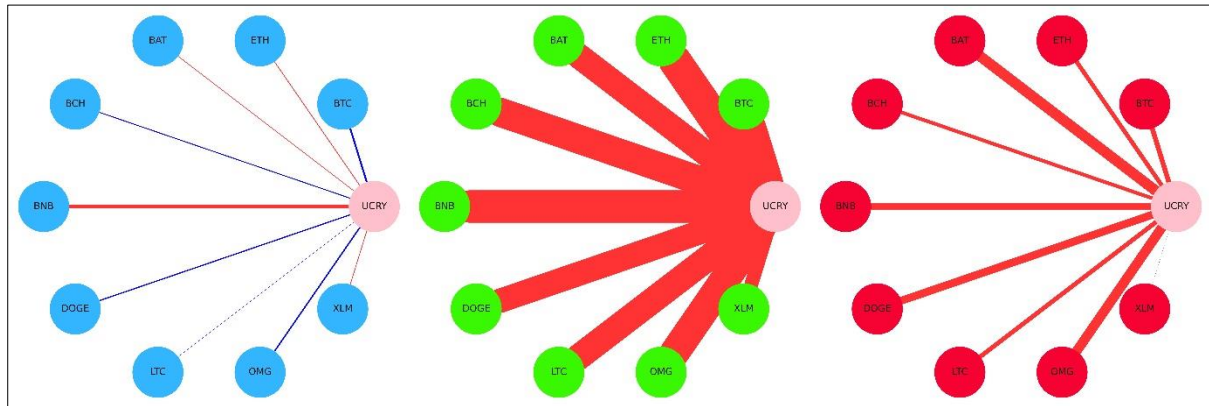
**Figure 2. GPRD Spillover**

Figure 3 illustrates the spillovers between UCRY and the selected set of cryptocurrencies.<sup>4</sup> The three sub-figures (left to right) show frequency 1 (1 week), frequency 2 (1 to 4 weeks), and frequency 3 (4 weeks to infinity), respectively. For frequency 1, OMG, LTC, DOGE, BCH, and BTC receive net spillovers from UCRY, but none of the cryptocurrencies receive spillovers at frequencies 2 and 3. The results indicate that uncertainty about specific cryptocurrency policies affects the weekly prices of BTC, BCH, DOGE, OMG, and LTC in the short term

<sup>3</sup> The corresponding spillovers table can be found in the Appendix.

<sup>4</sup> The corresponding spillovers table can be found in the Appendix.

(frequency 1), as investors react to policy changes by becoming more risk-averse and selling off their holdings. However, this uncertainty does not seem to have a longer term effect (>1 week). Interestingly, these cryptocurrencies become net spillover transmitters over longer horizons to UCRY, suggesting their price and market dynamics impact overall uncertainty in the cryptocurrency market.



**Figure 3. UCRY spillover**

Figures 4 and 5 provide a visualization of the total connectedness between GPRD and cryptocurrencies and between UCRY and cryptocurrencies. The results indicate that the magnitude of total connectedness increases as the time horizon extends from short- to medium- to long-term. For the case of GPRD and cryptocurrencies, the total connectedness for frequency 1 (1 week), frequency 2 (1 to 4 weeks), and frequency 3 (4 weeks to infinity) are 68.90%, 72.05%, and 74.98%, respectively. These results suggest that changes in GPRD are highly connected to changes in the selected set of cryptocurrencies and that this connection becomes stronger as the time horizon extends.

Similarly, for the case of UCRY and cryptocurrencies, the total connectedness for frequency 1, frequency 2, and frequency 3 are 69.35%, 70.36%, and 74.65%, respectively. This result suggests that changes in UCRY are also highly connected to changes in the selected set of cryptocurrencies and that this connection becomes stronger as the time horizon extends. These findings highlight the importance of understanding the interconnectedness and spillover effects within the cryptocurrency market and the potential impact of policy and regulatory changes on the overall level of uncertainty in the market. The fact that total connectedness increases with the time horizon suggests that investors and market participants should be mindful of longer-term trends and potential spillover effects when making investment decisions.

It is important to note here that the differing impact of GPRD and UCRY on cryptocurrencies stems from the multifaceted nature of geopolitical risks, the unique attributes of individual cryptocurrencies, the role of market sentiment, and the specific focus of each index. While GPRD casts a wide net over global political events, UCRY delves into the inherent uncertainties specific to the cryptocurrency sector.



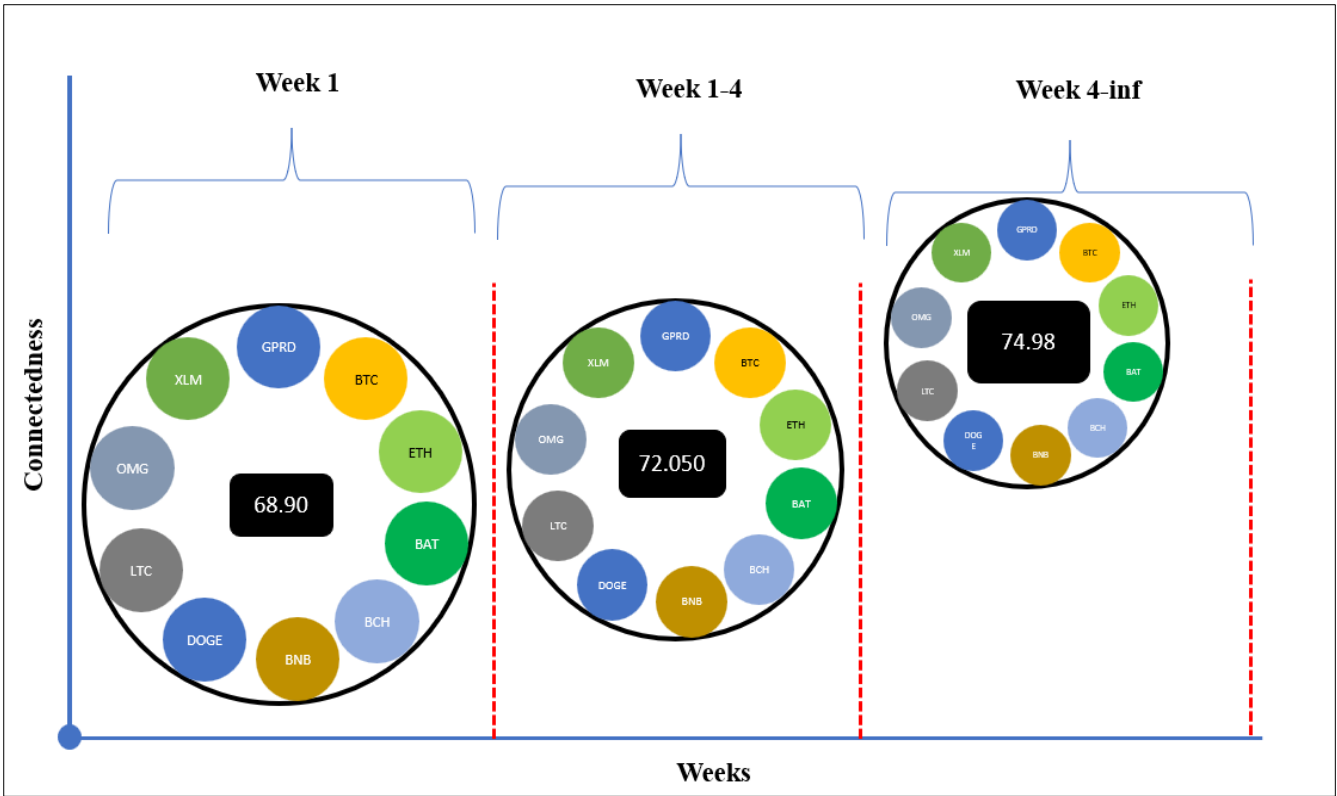


Figure 4. Connectedness Between GPRD and Cryptocurrencies

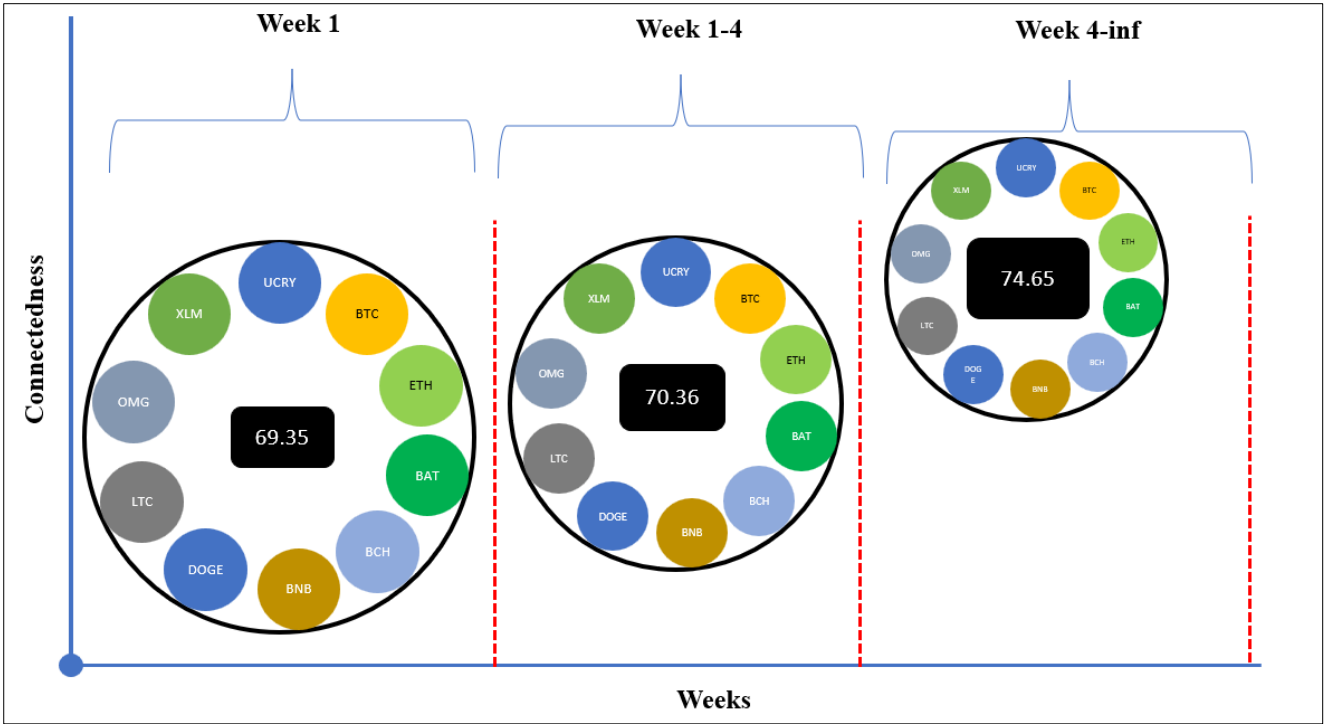


Figure 5. Connectedness Between UCRY and Cryptocurrencies

#### 4. Concluding Remarks

The present study sheds light on the spillover effects and interconnectedness between geopolitical risk, uncertainty related to cryptocurrencies, and prices of a selected set of major cryptocurrencies: Bitcoin, Ethereum, Basic Attention Token, Bitcoin Cash, Binance Coin, Dogecoin, Litecoin, OmiseGO, and Stellar Lumens.

Our findings indicate that among the nine cryptocurrencies examined, Dogecoin is the most sensitive to policy and regulatory risk changes, as spillover effects from changes in geopolitical risk impact it over all three horizons. Moreover, Binance Coin, Bitcoin Cash, and Ethereum are net receivers of spillovers from geopolitical risk over longer time horizons, indicating their time-dependent sensitivity to policy and regulatory risk. We also find that short-term uncertainty related to cryptocurrencies affects the prices of BTC, BCH, DOGE, OMG, and LTC, with investors and traders displaying a knee-jerk reaction to policy changes. However, over longer time horizons, all cryptocurrencies become net transmitters of spillovers to uncertainty related to cryptocurrencies. Our study highlights the importance of understanding the interconnectedness and spillover effects within the cryptocurrency market and the potential impact of policy and regulatory changes on the overall level of uncertainty in the market. These findings significantly impact investors, policymakers, and regulators in managing risks in cryptocurrencies' rapidly evolving and interconnected world.

#### References

- Akyildirim, E., Aysan, A. F., Cepni, O., & Darendeli, S. P. C. (2021). Do investor sentiments drive cryptocurrency prices?. *Economics Letters*, 206, 109980.
- Al Mamun, M., Uddin, G. S., Suleman, M. T., & Kang, S. H. (2020). Geopolitical risk, uncertainty and Bitcoin investment. *Physica A: Statistical Mechanics and Its Applications*, 540, 123107.
- Al-Shboul, M., Assaf, A., & Mokni, K. (2022). When bitcoin lost its position: Cryptocurrency uncertainty and the dynamic spillover among cryptocurrencies before and during the COVID-19 pandemic. *International Review of Financial Analysis*, 83, 102309. <https://doi.org/10.1016/j.irfa.2022.102309>
- Al-Shboul, M., Assaf, A., & Mokni, K. (2023). Does economic policy uncertainty drive the dynamic spillover among traditional currencies and cryptocurrencies? The role of the COVID-19 pandemic. *Research in International Business and Finance*, 64, 101824. <https://doi.org/10.1016/j.ribaf.2022.101824>
- Bação, P., Duarte, A. P., Sebastião, H., & Redzepagic, S. (2018). Information Transmission Between Cryptocurrencies: Does Bitcoin Rule the Cryptocurrency World? *Scientific Annals of Economics and Business*, 65(2), 97–117. <https://doi.org/10.2478/saeb-2018-0013>
- Balcilar, M., Bonato, M., Demirer, R., & Gupta, R. (2018). Geopolitical risks and stock market dynamics of the BRICS. *Economic Systems*, 42(2), 295–306. <https://doi.org/10.1016/j.ecosys.2017.05.008>
- Baruník, J., & Křehlík, T. (2018). Measuring the frequency dynamics of financial connectedness and systemic risk. *Journal of Financial Econometrics*, 16(2), 271–296.

- Belzer, D., Mosey, G., Plympton, P., & Dagher, L. (2007). Home Performance with ENERGY STAR: Utility Bill Analysis on Homes Participating in Austin Energy's Program (No. NREL/TP-640-41903). National Renewable Energy Lab.(NREL), Golden, CO (United States).
- Bouri, E., Shahzad, S. J. H., Roubaud, D., Kristoufek, L., & Lucey, B. (2020). Bitcoin, gold, and commodities as safe havens for stocks: New insight through wavelet analysis. *The Quarterly Review of Economics and Finance*, 77, 156–164.
- Caldara, D., & Iacoviello, M. (2022). Measuring geopolitical risk. *American Economic Review*, 112(4), 1194-1225.
- Dasauki, M., & Kwarbai, J. (2021). COVID-19 Pandemic: Revisiting the Safe Haven Assets. <https://doi.org/10.13140/RG.2.2.21461.96485>
- Drożdż, S., Gębarowski, R., Minati, L., Oświęcimka, P., & Wątor, M. (2018). Bitcoin market route to maturity? Evidence from return fluctuations, temporal correlations and multiscaling effects. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 28(7), 071101.
- Elsayed, A. H., Gozgor, G., & Yarovaya, L. (2022). Volatility and return connectedness of cryptocurrency, gold, and uncertainty: Evidence from the cryptocurrency uncertainty indices. *Finance Research Letters*, 47, 102732. <https://doi.org/10.1016/j.frl.2022.102732>
- Fama, E. F., Fisher, L., Jensen, M. C., & Roll, R. (1969). The adjustment of stock prices to new information. *International economic review*, 10(1), 1-21.
- Haq, I. U., & Bouri, E. (2022). Sustainable versus Conventional Cryptocurrencies in the Face of Cryptocurrency Uncertainty Indices: An Analysis across Time and Scales. *Journal of Risk and Financial Management*, 15(10), 442. <https://doi.org/10.3390/jrfm15100442>
- He, H., & Wang, J. (1995). Differential information and dynamic behavior of stock trading volume. *The Review of Financial Studies*, 8(4), 919–972
- Ji, Q., Bouri, E., Roubaud, D., & Kristoufek, L. (2019). Information interdependence among energy, cryptocurrency and major commodity markets. *Energy Economics*, 81, 1042–1055. <https://doi.org/10.1016/j.eneco.2019.06.005>
- Kakinuma, Y. (2023). Hedging role of stablecoins. *Intelligent Systems in Accounting, Finance and Management*, isaf.1528. <https://doi.org/10.1002/isaf.1528>
- Khalifaoui, R., Gozgor, G., & Goodell, J. W. (2023). Impact of Russia-Ukraine war attention on cryptocurrency: Evidence from quantile dependence analysis. *Finance Research Letters*, 52, 103365. <https://doi.org/10.1016/j.frl.2022.103365>
- Koutmos, D. (2018). Return and volatility spillovers among cryptocurrencies. *Economics Letters*, 173, 122–127. <https://doi.org/10.1016/j.econlet.2018.10.004>
- Long, H., Demir, E., Będowska-Sójka, B., Zaremba, A., & Shahzad, S. J. H. (2022). Is geopolitical risk priced in the cross-section of cryptocurrency returns? *Finance Research Letters*, 49, 103131. <https://doi.org/10.1016/j.frl.2022.103131>
- Lucey, B. M., Vigne, S. A., Yarovaya, L., & Wang, Y. (2022). The cryptocurrency uncertainty index. *Finance Research Letters*, 45, 102147. <https://doi.org/10.1016/j.frl.2021.102147>

- Maitra, D., Ur Rehman, M., Ranjan Dash, S., & Hoon Kang, S. (2022). Do cryptocurrencies provide better hedging? Evidence from major equity markets during COVID-19 pandemic. *The North American Journal of Economics and Finance*, 62, 101776. <https://doi.org/10.1016/j.najef.2022.101776>
- Raza, S. A., Khan, K. A., Guesmi, K., & Benkraiem, R. (2023). Uncertainty in the financial regulation policy and the boom of cryptocurrencies. *Finance Research Letters*, 52, 103515. <https://doi.org/10.1016/j.frl.2022.103515>
- Sawarn, U., & Dash, P. (2023). Time and frequency uncertainty spillover among macro uncertainty, financial stress and asset markets. *Studies in Economics and Finance*. <https://doi.org/10.1108/SEF-11-2022-0518>
- Shahzad, S. J. H., Bouri, E., Roubaud, D., Kristoufek, L., & Lucey, B. (2019). Is Bitcoin a better safe-haven investment than gold and commodities? *International Review of Financial Analysis*, 63, 322–330.
- Shahzad, S. J. H., Bouri, E., Roubaud, D., & Kristoufek, L. (2020). Safe haven, hedge and diversification for G7 stock markets: Gold versus bitcoin. *Economic Modelling*, 87, 212–224.
- Tetlock, P. C. (2010). Does public financial news resolve asymmetric information? *The Review of Financial Studies*, 23(9), 3520–3557.
- Tetlock, P. C. (2014). Information transmission in finance. *Annu. Rev. Financ. Econ.*, 6(1), 365-384.
- Thampanya, N., Nasir, M. A., & Huynh, T. L. D. (2020). Asymmetric correlation and hedging effectiveness of gold & cryptocurrencies: From pre-industrial to the 4th industrial revolution☆. *Technological Forecasting and Social Change*, 159, 120195.
- Tong, Z., Goodell, J. W., & Shen, D. (2022). Assessing causal relationships between cryptocurrencies and investor attention: New results from transfer entropy methodology. *Finance Research Letters*, 50, 103351. <https://doi.org/10.1016/j.frl.2022.103351>
- Yarovaya, L., Matkovskyy, R., & Jalan, A. (2022). The COVID-19 black swan crisis: Reaction and recovery of various financial markets. *Research in International Business and Finance*, 59, 101521. <https://doi.org/10.1016/j.ribaf.2021.101521>