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On the resilience of cryptocurrencies: A quantile-frequency analysis of bitcoin and ethereum reactions in times of inflation and financial instability

Brahim Gaies [a,f], Najeh Chaâbane [b,c], Nadia Arfaoui [d], Jean-Michel Sahut [e,g,*]

[a] Department of Economics, Finance and Control, IPAG Business School, France
[b] QUARG UR17ES26, ESCT, Campus University of Manouba, Tunisia
[c] Higher Institute of Business Administration, University of Gafsa, Tunisia
[d] ESCT-Business School of Tunis, University of Manouba, Manouba, Tunisia
[e] IDRAC Business School, France
[f] IPAG Chair "Towards an Inclusive Company", Paris, France
[g] CEDRIS, Paris-Saclay University, France

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ABSTRACT

This study examines the resilience of Bitcoin and Ethereum to inflation and financial instability amidst major economic and political disruptions, including the U.S.-China trade war, the COVID-19 pandemic, the Ukrainian conflict, the collapse of Silicon Valley Bank, and the ensuing energy crisis. We employ wavelet coherence analysis and the quantile coherence method to unravel the complex relationship between these cryptocurrency prices, the 5-year breakeven inflation rate, and the U.S. Financial Stress Index (FSI), utilizing daily data from April 16, 2018, to April 14, 2023. Our results reveal that during turbulent times, investors adjust their Bitcoin holdings in response to inflation expectations, driving up Bitcoin prices in both the short and long term. However, Bitcoin's effectiveness as an inflation hedge diminishes in bearish market conditions, and it proves unreliable as a hedge against financial instability. The relationship between Ethereum and inflation expectations is found to be more context-dependent. Also, while Ethereum's vulnerability to financial instability is less persistent in the long run, it increases in bearish markets.

1. Introduction

Cryptocurrencies serve as a medium of exchange, similar to other digital currencies, by utilizing blockchain technology and robust cryptography to enable secure transactions, regulate the creation of additional units, and verify transactions (Angelis and da Silva, 2019). The first significant transaction using cryptocurrencies occurred in May 2010, when Bitcoin was used as a medium of exchange and had a value of $0.0025 (Hudson and Urquhart, 2019). Since then, Bitcoin's daily transactions have surged, reaching approximately 400,000 with a value of $35,000 in January 2021[1]. Bitcoin's success and popularity have inspired many imitators to launch similar cryptocurrencies with varying features (Ammous, 2018). In fact, as of November 2022, over 21,500 cryptocurrencies exist. Ethereum,

* Corresponding author at: IDRAC Business School, France.
E-mail address: jeanmichel.sahut@idrac-bs.fr (J.-M. Sahut).

[1] https://coinmarketcap.com/

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launched in 2015, is the second most dominant cryptocurrency after Bitcoin. Combined, Bitcoin and Ethereum account for about 70 % of the cryptocurrency market share.[1]

Although both Bitcoin and Ethereum networks are built on blockchain technology, there are several key differences that set them apart. Bitcoin is designed to store value in a decentralized manner, facilitating secure peer-to-peer transactions. Fundamentally, it is often considered a medium of exchange, akin to the Dollar (Baur and Dimpfl, 2021), as well as a speculative financial asset (Gaies et al., 2024). However, the Ethereum platform offers a more secure protocol and technology, providing additional functionality compared to Bitcoin. One appealing feature of the Ethereum platform is the use of smart contracts, which enable safer and faster automatic contract execution, making it more linked to innovation. While Ethereum allows for the development of applications with built-in smart contracts that utilize Ethereum as a form of payment, Bitcoin lacks this functionality. However, while Bitcoin has more established market presence compared to Ethereum, Ethereum boasts lower transaction costs and faster clearance compared to Bitcoin (Ammous, 2018). It is also worth noting that Ethereum transactions require only a few seconds for confirmation, whereas Bitcoin transactions can take minutes, but Ethereum may be more seen as a decentralized platform that allows developers to create and deploy various applications. Both Bitcoin and Ethereum operate without a central authority, as they were designed to function as peer-to-peer digital exchange systems. Unlike traditional fiat currencies, they are decentralized and are not supposed to be subject to traditional inflationary pressures and financial turmoil (Shi et al., 2020; Ciaian et al., 2015).

With the increasing success and popularity of cryptocurrencies, many researchers have focused on analyzing their potential as safe-haven assets, beyond their role of medium of exchange. Some studies assert that including Bitcoin in a portfolio could reduce overall risk (Selmi et al., 2018; Guesmi et al., 2019, Huynth et al., 2020, Kang et al., 2020; Matkovskyy et al., 2020), while others strongly dispute the notion of Bitcoin as a safe-haven asset due to its extreme volatility during market tensions (Klein et al., 2018, Smales, 2019, Gaies et al., 2024and long-term riskiness (Yarovaya et al., 2022; Gaies et al., 2024).These mixed results may stem from differences in data frequency (Urquhart and Zhang, 2019; Bouri et al., 2020; Umar et al., 2021), analysis periods (Bouri et al., 2017; Wen et al., 2022), and investment horizons (Corbet et al., 2018; Kumar, Padakandla 2022; Gök et al., 2022) considered by researchers. Until now, the safe-haven properties of cryptocurrencies other than Bitcoin have received relatively little attention. Among the few studies conducted in this area, Meshcheryakov and Ivanov (2020) explore whether Ethereum functions as a hedge, diversifier, or safe-haven asset. Their findings suggest that Ethereum acts as a hedge against the U.S. stock and gold markets and serves as a diversifier for the US Dollar. Bouri et al. (2020) examine the hedging and safe-haven properties of eight cryptocurrencies (i.e., Bitcoin, Ethereum, Ripple, Litecoin, Stellar, Dash, Nem, and Monero) against the S&P 500 and its ten sector indices using the Cross-quantilogram approach. Their results indicate that Bitcoin, Ripple, and Stellar, as well as Monero and Litecoin, function as safe havens for all US equities (and the US market-wide equity index), whereas Ethereum, Dash, and (Gaies et al., 2023) Nem only serve as hedges for specific equity sectors. Similarly, Feng et al. (2018) demonstrate through an extreme-value-theory-based method that Bitcoin and Ethereum are effective diversification assets for stocks but not safe havens.

Recent studies have started to explore how these characteristics vary during macroeconomic disturbances, particularly in relation to global financial instability as indicated by financial stress indexes (FSIs) and periods of high inflation. These insights suggest a dynamic and context-dependent role of cryptocurrencies in financial markets. Bouri et al. (2018) examined the relationship between the Global Financial Stress Index (FSI) and Bitcoin returns, covering the period from July 18, 2010, to December 29, 2017. Their research discovered a significant tail dependence between the FSI and Bitcoin returns. The study establishes Bitcoin as a safe haven against global financial stress. Zhang and Wang (2021) further explored the impact of financial stress in China and the U.S. on various financial assets, including Bitcoin and gold. They found that the U.S. FSI is a short-term influencer for Bitcoin, while the China FSI has a medium-term impact on gold during normal market conditions. Additionally, while gold prices are moderately affected by the U.S. FSI, Bitcoin shows lesser influence. Significantly, their results underscore the substantial impact of U.S. financial stress on Bitcoin. However, prior research has not specifically addressed the connection between the FSI and Ethereum. In a more recent study, Gaies et al. (2024) revealed a persistent link between U.S. financial stress and global cryptocurrency market volatility, particularly in extreme market conditions, although this correlation diminishes in the short term. Their findings indicate that both Ethereum and Bitcoin are not effective for hedging against risks in the banking sector and systemic risks. Nevertheless, these cryptocurrencies can offer short-term protection against stock market risks under stable market conditions.

On the other hand, research on the relationship between cryptocurrencies and inflation has yielded mixed results. Conlon et al. (2021) found only limited evidence that Bitcoin and Ethereum act as hedges during periods of rising inflation expectations. In contrast, Blau et al. (2021) observed that increases in Bitcoin's price significantly elevate forward inflation rates, thus showing its potential as an inflation hedge. Similarly, Choi and Shin (2022) noted Bitcoin's appreciation in response to positive inflation shocks. Contrasting these findings, Matkovsky and Jalan (2021) determined that Bitcoin paired with the Japanese Yen and British Pound could hedge against inflation in Japan and the UK, but this was not the case for Bitcoin against the U.S. dollar. Smales (2022) found that cryptocurrencies and gold are effective as short-term hedges against U.S. inflation. However, in the long term, only gold can fulfill this role. Lastly, Sakurai and Kurosaki (2023) reported that Bitcoin, Ethereum, and Litecoin have improved as inflation hedges since the post-COVID-19 reopening of the U.S. economy.

Based on the discussion above, this paper investigates the responses of Bitcoin and Ethereum, the two major cryptocurrencies, to two significant recent macroeconomic disturbances: inflation and financial instability. These disturbances are connected to real economic and political disruptions, including the US-China trade war, the COVID-19 pandemic, the conflict in Ukraine with its subsequent energy crisis, and the Silicon Valley bank collapse, as highlighted in various studies (Pandey et al., 2023a; Pandey et al., 2023b; Kumari et al., 2023; Naeem and Arfaoui, 2023; Abbassi et al., 2023; Akhtaruzzaman et al., 2022; Chen et al., 2022; Goodell et al., 2020). The study utilizes daily data spanning from April 16, 2018, to April 14, 2023, encompassing 1261 business days. This data set includes Bitcoin and Ethereum prices, the U.S. 5-year inflation rate as a proxy for expected inflation, and the U.S. Financial Stress

Index (FSI) as an indicator of financial instability. Methodologically, the study employs two advanced techniques: wavelet coherence and quantile coherency (Baruník and Kley, 2019). By doing so, the study aims to make three significant contributions to the existing literature.

First, our study is quite novel in its comprehensive examination of Bitcoin and Ethereum's responses to inflation and financial instability. Previous analyses often overlook Ethereum, which accounts for 18 % of the total crypto-currency market capitalization. They also tend to consider financial instability or inflation in isolation, preventing a direct comparison between the inflation and FSI hedging capabilities of crypto-currencies within the same study, time period and methodological framework.

Second, to the best of our knowledge, this is the first paper applying Baruník and Kley's (2019) novel coherency quantile method to the study of crypto-currencies' responses to inflation and FSI. This method allows us to see how time-frequency dependencies move from bearish to bullish market conditions. The superiority of the quantile consistency approach over traditional econometric techniques, such as OLS regression, causality in quantile, and quantile-on-quantile methods, is due to the fact that it shows remarkable resistance to outliers, heavy tails, and non-normal distributions that are common in financial series.

Finally, we complement previous studies on the hedging properties of crypto-currencies by considering not only the pre-COVID-19 period, but also the post-COVID-19 era. This allows us to encompass major recent global events, including the U.S.-China trade war, the conflict in Ukraine, and the subsequent energy crisis. In addition, by offering a more comprehensive understanding of the impact of inflation and financial instability on Bitcoin and Ethereum, the two leading cryptocurrencies, we provide fresh and valuable recommendations to policymakers and investors to make appropriate decisions and establish suitable regulations and strategic plans, especially in times of macro-disturbances.

The key findings of our study suggest that Bitcoin offers a reliable hedge against inflation during turbulent times, providing effective coverage over both short-term (16–32 days) and long-term (64–128 days) investment horizons. However, this protective role diminishes in bearish market conditions. Ethereum demonstrates a similar pattern, but its hedging capacity is largely confined to the short and medium term (16–64 days) and weakens during bearish phases. Both Bitcoin and Ethereum markets exhibit significant exposure to financial instability during periods of disruption, particularly within short- and medium-term investment periods. Notably, Ethereum's vulnerability, while not as enduring as Bitcoin's over the long term, shows greater sensitivity during bearish market conditions.

The remaining sections of the paper are organized as follows. Section 2 reports a review of the relevant literature. Section 3 furnishes a description of the data and the methodology approach. Section 4 outlines and discusses the main empirical results. Section 5 draws the key conclusions, and lastly, Section 6 provides the main implications for investors and policymakers.

2. Literature review

2.1. Cryptocurrencies and inflation

Theoretically speaking, the rise of inflation rate prompts investors to search for a hedging asset to safeguard against the erosion of the value of money, which diminishes purchasing power and the standard of living. Similarly, inflation is an important investment risk as it decreases the real value of assets (Phochanac et al., 2022). Thus, this contributes to an increased demand for perceived hedging assets. Bodie (1976) outlines three key attributes that define the inflation-hedging capabilities of an asset. First, an asset can be considered as an inflation hedge if its return is at least equal to the inflation rate. Second, it is an asset that diminishes the variance or uncertainty associated with the future return of another asset in times of high inflation. Finally, the last attribute, commonly employed in almost all empirical studies of inflation hedging, reveals that an asset can be considered as an inflation hedge if there exists a positive correlation between inflation and this asset's return. Conversely, according to Fama and Schwert (1977), an asset appears as a perverse hedge against inflation if the correlation is negative.

Due to the rise of global uncertainty and the proliferation of economic and financial macro-disturbances from the Covid-19 pandemic to the Ukrainian conflict and beyond, a growing debate has emerged regarding the potential of certain cryptocurrencies to serve as a hedging tool against inflation in response to rising inflation rates (Phochanac et al., 2022). An argument in favor of cryptocurrencies suggests that their computational nature generally limits their supply, making them resilient to inflationary pressures (Sakurai and Kurosaki, 2023). This argument aligns with the economic reasoning behind utilizing gold as an inflation hedge, as gold's limited supply is attributed to its physical nature, making it robust against inflation. Consequently, cryptocurrencies are occasionally referred to as "digital gold" in light of this analogy (Smales, 2022). In this spirit, Bitcoin might be considered as an effective hedge against inflation risk (Choi and Shin, 2022). Specifically, the high demand for, limited supply, and monetization of Bitcoin can provide the potential to protect against rising prices, aligning with the definition of an inflation hedge (Reilly et al., 1970; Cagan, 1974). Consequently, previous studies have paid particular attention to the Bitcoin–inflation relationship, but the empirical evidence is not always conclusive. More precisely, most studies reveal that Bitcoin either cannot hedge against inflation or can hedge against inflation only in the short run following certain economic shocks. For instance, Conlon et al. (2021) used wavelet time-scale techniques to examine the link between cryptocurrency (i.e., Bitcoin, Ethereum) prices and forward inflation expectations. Their findings show very limited evidence suggesting that Bitcoin and Ethereum act as a hedge during periods of increasing forward inflation expectations. This empirical evidence reveals that cryptocurrencies do not hedge against increases in forward inflation expectations. Blau et al. (2021) investigated the relationship between Bitcoin and forward inflation expectation rates using a vector autoregressive process. Their results show that an unexpected increase in the price of Bitcoin leads to a significant and persistent increase in the forward inflation rate. The authors also reveal that Bitcoin may be used as a hedge against inflation. Choi and Shin (2022) report that Bitcoin appreciates against positive inflation (or inflation expectation) shocks, revealing its inflation-hedging property supported by investors. Matkovsky and Jalan (2020), through a Quantile-on-Quantile regression, find that Bitcoin to JPY (Bitcoin to GBP) can hedge against inflation in Japan (UK), whereas Bitcoin to USD (BTC/USD) could not hedge against realized inflation. More recently, Smales (2023) reveal a positive association between gold/cryptocurrency (including Bitcoin and Ethereum) returns and changes in U.S. inflation. They also report that both cryptocurrencies and gold appear as effective hedgers against inflation in the short run. Nevertheless, unlike gold, there is an absence of any evidence suggesting that cryptocurrencies could be used to hedge against inflation in the long run. More recently, Sakurai and Kurosaki (2023) report that Bitcoin, Ethereum, and Litecoin exhibit better inflation hedging since the reopening of the U.S. economy after the COVID-19 crisis.

2.2. *Cryptocurrencies and financial instability*

Intuitively, the instability of the entire official financial system, i.e., financial instability (Ozcelebi, 2020; Gaies and Chaâbane, 2023; Aloui et al., 2023; Kanzari et al., 2023), may drive investors to seek alternative investment opportunities that promise high returns in a relatively short period. This quest for lucrative investments can increase interest in the cryptocurrency market, as cryptocurrencies are known for their potential for rapid price appreciation. Such a scenario would lead to a surge in cryptocurrency prices. Conversely, financial instability may also trigger a shift towards risk aversion among investors, thus leading them to more conservative investment, perceived as less volatile and more secure compared to cryptocurrencies. This is even more likely to happen due to the strong link between crypto-demand and investor sentiment (Chen et al., 2020; Gaies et al., 2021; 2022) during turbulent times. The

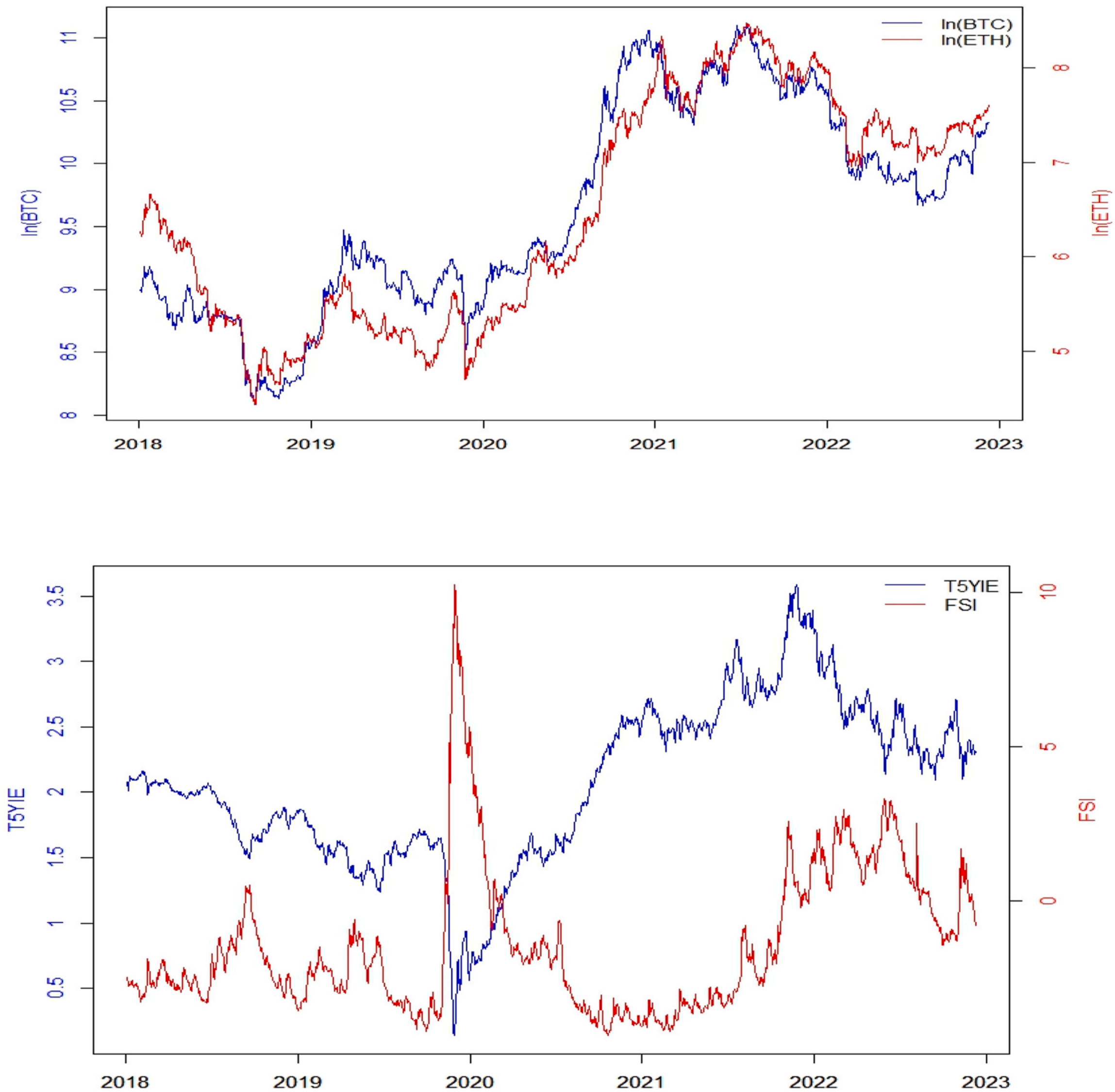

Fig. 1. BTC vs ETH and T5YIE vs FSI plots.

outcome is often a decrease in cryptocurrency prices.

The dual theoretical impact of financial instability on the cryptocurrency market underlines its complex nature. In the recent empirical literature, to our knowledge, there are four main studies explicitly devoted to this topic. Bouri et al. (2018) implemented a copula-based method to delve into the correlation between Bitcoin returns and the Global Financial Stress Index (GFSI), a global financial instability indicator. They uncovered that Bitcoin returns are significantly influenced by GFSI at the distribution's extreme tails, suggesting that Bitcoin returns are more susceptible to financial instability during periods of exceptional market performance, both poor and superior. Nevertheless, Bitcoin serves as a safe haven during standard market conditions. An exploration into how market conditions affect the linkages between the Financial Stress Index (FSI) and gold and Bitcoin markets was undertaken by Zhang and Wang (2021). Applying a GARCH model, they deduced that circumstances such as the immigration crisis and the Sino-US trade tensions have fortified these linkages. This is attributed to the "wait and see" stance adopted by economic entities. This approach implies that businesses and households are inclined to postpone their investments until the uncertainty dissipates. Interestingly, Zhang and Wang (2021) observed that gold is more reactive to financial instability in the US than Bitcoin, though this pattern does not hold true for China. Most recently, a study mirroring that of Zhang and Wang (2021) was conducted by (Hoque and Low, 2022), but with the use of OLS and quantile regression analysis, in addition to varying financial stress classifications. Their investigation revealed that, apart from during the Covid-19 period, Bitcoin returns are swayed by equity valuation and shifts in the price of safe assets. Conversely, during the pandemic, Bitcoin's response is more pronounced to credit spread and safe asset price fluctuations within the higher quantiles. Finally, using the newly introduced Cryptocurrency VIX index, wavelet coherence analysis, quantile wavelet coherency method, and non-parametric causality testing, a new study by Gaies et al., (2024) shows a notable correlation and causality between the volatility in the global cryptocurrency market and U.S. financial instability. These linkages appear to be enduring, particularly in extreme market scenarios, while they weaken in short time frames. The authors also found that cryptocurrencies are not effective in mitigating risks tied to the banking sector and systemic issues. However, they demonstrate potential as short-term hedges against stock market risks under conditions of market stability. Furthermore, the research reveals an interactive risk transmission between the stock market and the cryptocurrency market, particularly over a medium-term horizon.

Despite this significant body of work, a lack of insight is found regarding the resilience of Bitcoin and Ethereum to inflation and financial instability taken together during periods of major economic and political turmoil. Consequently, in this study, we employ a novel and advanced econometric approach that can suitably identify how time-frequency dependencies move from bearish to bullish market conditions in the context of major economic and political disruptions, including the U.S.-China trade war, the COVID-19 pandemic, the Ukrainian conflict, the collapse of Silicon Valley Bank, and the ensuing energy crisis.

3. Data and methodology

3.1. Data

In our study, we analyze price data for Bitcoin (BTC) and Ethereum (ETH). Along with this, the 5-year U.S. inflation rate (T5YIE) is utilized as a measure of anticipated inflation, while the U.S. Financial Stress Index (FSI) serves as an indicator of financial instability. The dataset comprises daily observations from April 16, 2018, to April 14, 2023, amounting to a total of 1261 data points. This period is highly interesting as it overlaps with important contemporary developments, including the trade war between the U.S. and China, the COVID-19 pandemic, the conflict in Ukraine, and the ensuing global energy crisis. Trends in BTC, ETH, T5YIE and FSI are shown in Fig. 1. Significant peaks and troughs are observed during the U.S.-China trade war, the COVID-19 recession and recovery, the conflict in Ukraine, and the subsequent energy crisis. This evidence underlines the severity of these events on global economy and financial market (Charfeddine et al., 2020; Boubaker et al., 2022;Gaies, 2022; Gaies et al., 2022; Umar et al., 2022; Liu et al., 2022; Akhtaruzzaman et al., 2023; Boubaker et al., 2023).However, the sharpest increases (for BTC, ETH, and FSI) and decreases (for T5YIE) were seen at the beginning of the COVID-19 pandemic.

Table 1 presents the primary statistics and goodness-of-fit assessments for the dataset. The skewness test returns positive results for the ln(BTC), ln(ETH), and FSI variables, while the T5YIE variable exhibits a slightly negative result. This indicates that the distribution

Table 1
Statistics and goodness-of-fit tests.

	ln(BTC)	ln(ETH)	T5YIE	FSI
Descriptive statistics				
Mean	9.6309	6.4691	2.0630	-1.4015
SD	0.8250	1.1823	0.6217	2.3593
Skewness	0.1082	0.0717	-0.1199	1.5382
Kurtosis	1.8061	1.4992	2.7857	6.1413
JB test	77.351***	119.42***	5.4368*	1015.8***
BDS test	473.4672***	653.6598***	364.8121***	148.638***
Nonlinear Unit Root tests				
Kruse (2011)	36.0170***	36.2611***	31.8413***	175.2949***
Hu and Chen (2016)	1340.299***	559.0877***	949.993***	250.2755***

Note: Asterisks (* and ***) stand for significance levels of 10 % and 1 %, respectively. The critical value of the (Kruse, 2011) and (Hu and Chen, 2016) tests at level 1 % are 13.15 and 15.12, respectively.

of the time series data is almost symmetric. The kurtosis test reveals small values, ranging from 1 to 6, indicating that the underlying sample is somewhat leptokurtic, with a sharp peak around the mean compared to a standard Gaussian distribution. These statistics are further confirmed by the Jarque-Bera tests. The large values of the Brock-Dechert-Scheinkman (BDS) statistics suggest that the null hypothesis, stating that the series are linear, should be rejected. Consequently, Kruse (2011) and Hu and Chen (2016) tests were employed to investigate nonlinear unit root tests. They confirm the stationarity of the data.

3.2. Methodology

3.2.1. Wavelet coherence

Wavelets are a type of waveform that have a zero mean and bounded energy models, and are typically denoted $\psi(k)$ (Gençay, R. et al. 2001). The term "mother wavelet" is used to describe $\psi(k)$ because it generates a set of wavelet bases that can be expressed as a function of both scale a and time position b. The set of (a, b) coordinates in a two-dimensional plane used to describe the time-frequency characteristics of scale-space dimensions. Wavelets decompose a signal Y_k into elementary functions known as daughters $\psi_{a,b}(k)$, such as

$$\psi_{a,b}(k) = \frac{1}{\sqrt{a}}\psi\left(\frac{k-b}{a}\right), a > 0 \tag{1}$$

The continuous wavelet transform of a given time series $y(k)$ can be written as:

$$W_y(a,b) = \frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} y(k)\psi\left(\frac{k-b}{a}\right)dk = \langle y, \psi_{a,b}\rangle \tag{2}$$

Many intriguing measures can be formulated within the wavelet domain. The wavelet power spectrum (also known as scalogram), denoted as

$$WP_y = |W_y(a,b)|^2 \tag{3}$$

The wavelet scalogram assesses the impact on the series' variability at each time and frequency. Similarly, the cross-wavelet spectrum is another noteworthy measure that captures the co-variation between two series within the time-frequency domain. Given two time series $y_1(k)$ and $y_2(k)$, the cross-wavelet spectrum can be expressed as follows:

$$WP_{y_1y_2}(a,b) = WP_{y_1}(a,b)WP^*_{y_2}(a,b) \tag{4}$$

where $WP^*_{y_2}(a,b)$ represents the conjugate of $WP_{y_2}(a,b)$.

According to Aguiar-Conraria and Soares (2011) and in analogy with the concept of coherency used in Fourier analysis, the complex wavelet coherency is defined by:

$$\varrho_{y_1y_2} = \frac{S\left(WP_{y_1y_2}(a,b)\right)}{\left[S\left(|W_{y_1}(a,b)|^2\right) \quad S\left(|W_{y_2}(a,b)|^2\right)\right]^{1/2}} \tag{5}$$

Where $S(.)$ denotes smoothing in both time and scale. Aguiar-Conraria and Soares (2011) defined the wavelet coherency, denoted by $R_{y_1y_2}$, as the absolute value of the complex wavelet coherency, i.e.

$$R_{y_1y_2} = \frac{\left|S\left(WP_{y_1y_2}(a,b)\right)\right|}{\left[S\left(|W_{y_1}(a,b)|^2\right) \quad S\left(|W_{y_2}(a,b)|^2\right)\right]^{1/2}} \tag{6}$$

with $0 \le R_{y_1y_2} \le 1$. The wavelet coherency measures the strength of the relationship between y_1 and y_2 over time and across scales. Thus, by analyzing the wavelet coherency plot, one can identify areas in the time-frequency space where the link is stronger and detect time and frequency-related characteristics. The angle $\phi_{y_1y_2}$ of the complex coherency is called the phase-difference, i.e. phase lead of y_1 over y_2, and it is expressed as follows:

$$\phi_{y_1y_2} = \text{Arctan}\left(\frac{\Im\left(S\left(WP_{y_1y_2}(a,b)\right)\right)}{\Re\left(S\left(WP_{y_1y_2}(a,b)\right)\right)}\right) \tag{7}$$

When the phase difference between two time series is zero, it signifies that they exhibit synchronous movement at a given time-frequency. Additionally, if the value of $\phi_{y_1y_2}$ falls within the range of [0, π/2], it indicates that both series are in phase, with y_1 leading y_2. Conversely, if $\phi_{y_1y_2}$ lies within the range of [-π/2, 0], it implies that both series are in phase, but y_2 is leading. Alternatively, when $\phi_{y_1y_2}$ is in the range of [π/2, π], it reveals an out-of-phase relationship with y_2 taking the lead. Similarly, if $\phi_{y_1y_2}$ is within the range of [-π, -π/2], it suggests an out-of-phase relationship with y_1 as the leading component.

3.2.2. Quantile coherency

Baruník and Kley (2019) introduced the quantile coherency approach, which provides a powerful tool for analyzing the interconnectedness between distribution quantiles and frequencies of joint distributions. This method allows for a more comprehensive analysis of the structure and dynamics of dependencies between two time series. The quantile coherency approach is particularly valuable in the analysis of extreme values, as it focuses on the lower and upper tails of each distribution. By exploring the relationships between distribution quantiles at different frequencies, it is possible to gain a deeper understanding of the underlying dependence structure of the time series being studied. Overall, the quantile coherency approach is a valuable analytical tool that can provide new insights into the complex dynamics of time series data.

According to Baruník and Kley (2019) the quantile coherency kernel is given by:

$$\nabla^{y_1y_2}\left(\omega:\tau_{y_1},\tau_{y_2}\right)=\frac{q^{y_1y_2}\left(\omega:\tau_{y_1},\tau_{y_2}\right)}{\sqrt{q^{y_1y_1}\left(\omega:\tau_{y_1},\tau_{y_2}\right)q^{y_2y_2}\left(\omega:\tau_{y_1},\tau_{y_2}\right)}} \tag{8}$$

Where $-\pi<\omega<\pi$ and$(\tau_{y_1},\tau_{y_2})\in[0,1]$. $q^{y_1y_1}$and$q^{y_2y_2}$ denote the quantile spectral densities of the two processes $y_1(t)$ and$y_2(t)$ while $q^{y_1y_2}$indicate the quantile cross spectral densities.

Following Baruník and Kley (2019), the terms$q^{y_1y_1}$, $q^{y_2y_2}$ and $q^{y_1y_2}$ are calculated using the matrix of quantile cross-covariance kernels$\Gamma_k(\tau_{y_1},\tau_{y_2})=(\gamma_k^{y_1y_2}(\tau_{y_1},\tau_{y_2}))_{y_1,y_2=1,\dots,d}$ where

$$\gamma_k^{y_1y_2}(\tau_{y_1},\tau_{y_2})=\operatorname{cov}\left(I\left\{y_1(t+k)\le f_{y_1}(\tau_{y_1})\right\},I\left\{y_2(t+k)\le f_{y_2}(\tau_{y_2})\right\}\right) \tag{9}$$

$k\in\mathbb{Z}$, $(\tau_{y_1},\tau_{y_2})\in[0,1]$ and $I\{A\}$ specifies the indicator function of the event A. Varying k can yield important information about the serial dependence, while selecting $y_1\neq y_2$ allows us to gain valuable information about cross-sectional dependence.In the frequency domain, Baruník and Kley (2019) show that the previously mentioned assumptions result in the following matrix of quantile cross-spectral density kernels:

$$q(\omega:\tau_{y1},\tau_{y2})=(q^{y_1y_2}(\omega:\tau_{y1},\tau_{y2}))_{y_1,y_2=1,.,d} \tag{10}$$

Where,

$$q^{y_1y_2}\left(\omega:\tau_{y_1},\tau_{y_2}\right)=(2\pi)^{-1}\sum_{k=-\infty}^{\infty}\gamma_k^{y_1y_2}(\tau_{y_1},\tau_{y_2})e^{-ik\omega} \tag{11}$$

According to Baruník and Kley (2019), when the value of $\left|\nabla^{y_1y_2}\left(\omega:\tau_{y_1},\tau_{y_2}\right)\right|^2$is close to one, it indicates a strong and reliable relationship between the variables under investigation.

In order to examine the coherence of the data, our research utilized the quantile coherency approach with a focus on three specific

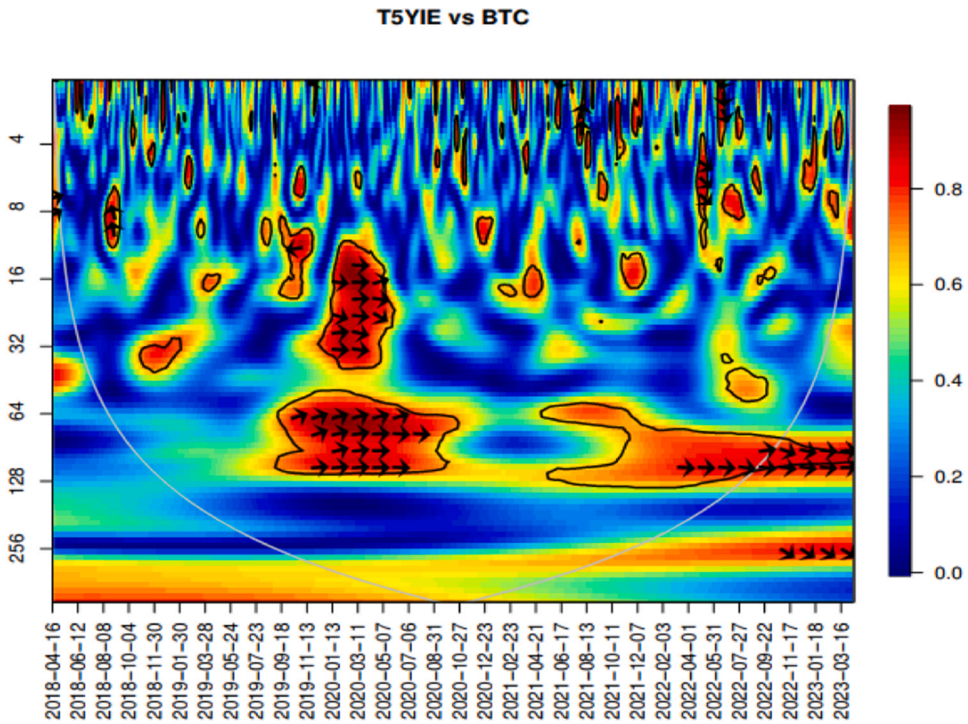

Fig. 2. Wavelet coherence: BTC and T5YIE.

quantiles (0.05, 0.50, and 0.95) across three distinct time frequencies: short term (one week), medium term (one month), and long term (one year). This analytical framework allowed us to explore the interdependence between different quantiles of the distribution, providing a more comprehensive understanding of the underlying structure and dynamics of studied the time series.

4. Empirical results

4.1. Wavelet coherence analysis

Numerous recent studies on the crypto market have demonstrated that its dynamics evolve over time and across various frequencies (Bouri et al., 2017). Brutal deviations in cryptocurrency and considerable shifts in trading volumes and prices occur across time and trading frequencies. This has led us to use the wavelet coherence method to explore the time and frequency domain dependencies between Bitcoin (BTC), Ethereum (ETH), inflation (T5YIE), and financial instability (FSI). This approach allows us to capture short-, medium-, and long-term relationships between the crypto market, financial instability, and inflation. Figs. 2-5 present the estimated wavelet coherence for pairs of Bitcoin and Ethereum with inflation and financial instability. The time scale spans from 1 (one day) to 256 days (one business year), covering short to long-term investment horizons using daily data from April 16, 2018, to April 14, 2023. In Figs. 2–5, time horizons are plotted on the horizontal (x-axis), frequencies in business days are plotted on the vertical (y-axis), and dependencies at the 5 % statistical significance level are located inside the grey contour. Strong dependencies are denoted by yellow and orange-colored areas, while green and blue areas represent weak dependencies. The black arrows within the colored areas indicate the direction of the dependencies and their lead/lag phase relationships. Arrows pointing right (in-phase) signify positive dependencies, whereas arrows pointing left (out-of-phase) denote negative dependencies. When arrows point towards the upper right or lower left, T5YIE and FSI are leading. On the other hand, arrows pointing towards the lower right or upper left indicate that BTC and ETH are leading.

Fig. 2 shows strong positive (in-phase) dependencies between BTC and T5YIE for the 16–32-day scale from 12/11/2019–7/5/2020, and the 64–128-day scale from 18/9/2019–31/8/2020 and from 7/12/2021–22/9/2022, with T5YIE relatively clearly in the lead. These results suggest that Bitcoin prices and expected inflation move in tandem over these time periods, indicating that higher expected inflation may have a positive impact on Bitcoin prices. This influence spans both short- and long-term investment horizons as the 16–32-day range during the first period (12/11/2019–7/5/2020) represents a short- to medium-term relationship, while the 64–128-day range during the second period (9/18/2019–8/31/2020 and 7/12/2021–9/22/2022) reflects a medium- to long-term relationship.

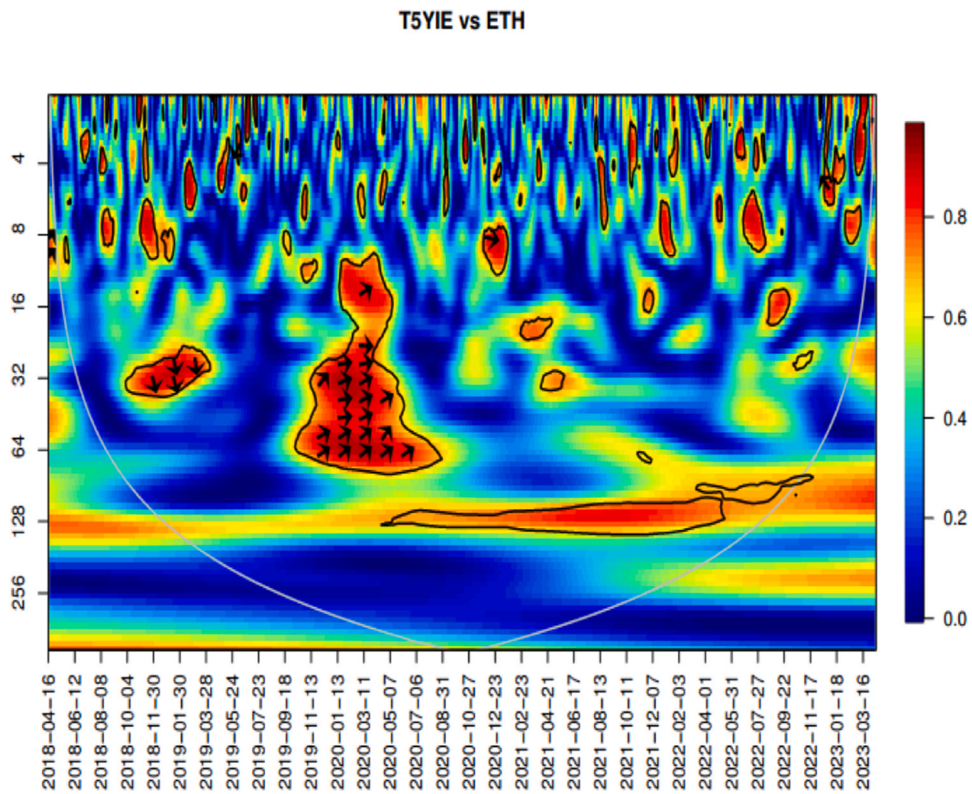

Fig. 3. Wavelet coherence: ETH and T5YIE.

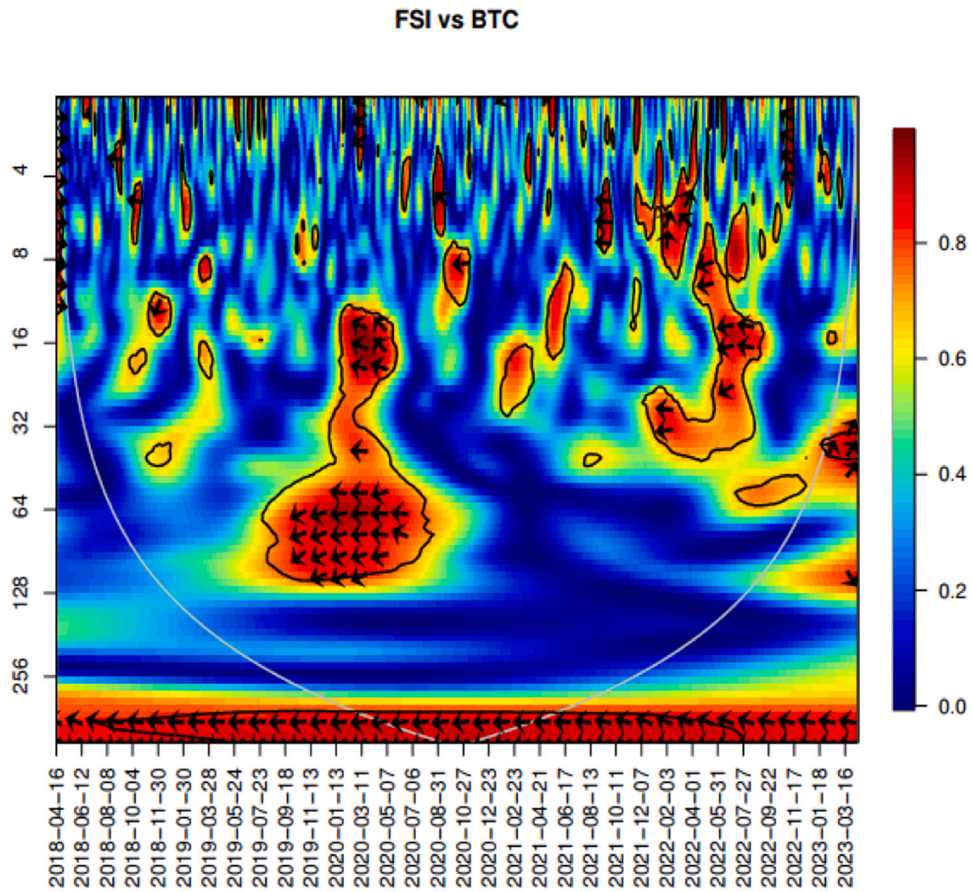

Fig. 4. Wavelet coherence: BTC and FSI.

It appears that crypto-currency investors are responding to changes in inflation expectations by adjusting their Bitcoin positions, resulting in higher Bitcoin prices during these periods. Importantly, these periods coincide with macroeconomic events, changes in market sentiment, and changes in monetary policy, which provides context for the T5YIE-BTC relationship (Akhtaruzzaman et al., 2021;Pandey and Kumari, 2021). In fact, the COVID-19 pandemic led to widespread economic uncertainty and unprecedented monetary policy actions by central banks around the world, which encouraged liquidity through stimulus programs (Boubaker et al., 2022). As a result, inflation expectations could have been positively affected, and investors could have turned to Bitcoin as a hedge against potential inflation. The post-COVID-19 recovery phase, characterized by a global rebound in consumption, followed by the war in Ukraine and the resulting energy crisis, may have reinforced this relationship by positively influencing energy and commodity prices (Chortane and Pandey, 2022;Pandey et al., 2023c). These results prove that Bitcoin can serve as an inflation hedge and be seen as an alternative asset to protect investors' portfolios from eroding purchasing power. Bitcoin can also serve as a hedge against economic uncertainty related to government and central bank responses to depression and energy-induced inflationary pressures by implementing various monetary and fiscal policies, thereby influencing investor sentiment and behavior. Similarly, Bitcoin could hedge geopolitical uncertainty resulting from the war in Ukraine, as investors often seek alternative assets, such as Bitcoin, as a potential hedge against traditional market risks. These observations concur with the findings of Paule-Vianez et al. (2020), who demonstrated that Bitcoin serves as a protective tool in times of uncertainty. They further reinforce the view that Bitcoin is often seen as an effective hedge against inflation, even outperforming gold in this role, in line with Choi and Shin's (2022) research. Bitcoin's role as an inflation hedge is credited to its decentralized structure and limited supply. Currently, the total possible quantity of Bitcoin is capped at 21 million, creating a scarcity similar to precious metals like gold (Meynkhard, 2020). In times of rising inflation or currency devaluation concerns, investors typically turn to assets not subject to inflationary forces, particularly those with a finite supply. Furthermore, while Bitcoin is known for its significant short-term price volatility, its overall long-term growth and upward trend tend to surpass that of gold (Jin and Tian, 2024). This unique aspect renders Bitcoin a compelling choice for investors aiming to counteract the impact of inflation? Moreover, despite Bitcoin's greater volatility compared to gold, its notable long-term growth potential positions it as an effective instrument against inflationary pressures (Grinberg, 2012). Indeed, although Bitcoin experiences substantial short-term price fluctuations, its overall performance and sustained growth trajectory over the long term are greater than those of gold (Jin and Tian, 2024). This particular characteristic enhances Bitcoin's appeal to investors seeking to mitigate inflation's impact.

Fig. 3 presents similar results for the T5YIE-ETH dependencies in the time frequencies of 16–64 days from November 13, 2019 to

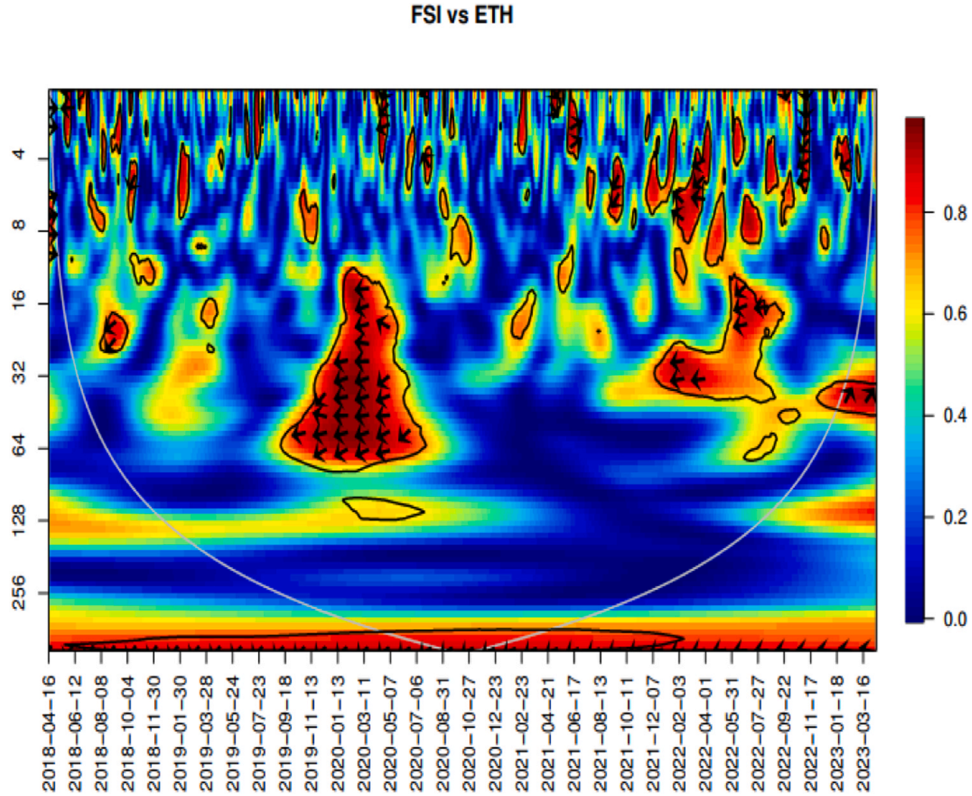

Fig. 5. Wavelet coherence: ETH and FSI.

August 8, 2020, during which inflation expectations appear to positively drive Ethereum prices. However, unlike the T5YIE-BTC relationship presented in Fig. 2, only the short- and medium-term dependencies between inflation expectations and Ethereum prices are clearly captured by the estimated wavelet coherence during the COVID-19 pandemic, and not during the post-COVID-19 recovery, the Ukraine war, or the resulting energy crisis. This result indicates that the relationship between inflation expectations (T5YIE) and Ethereum (ETH) prices is different from that between T5YIE and Bitcoin (BTC) prices. While both crypto-currencies show positive dependencies with inflation expectations during the COVID-19 pandemic, the relationship between T5YIE and ETH prices appears to be limited to short- and medium-term frequencies during this specific period. Furthermore, the lack of a clear relationship between T5YIE and ETH prices during the post-COVID-19 recovery, the war in Ukraine, and the resulting energy crisis suggests that Ethereum's hedging power against inflation expectations may be more context dependent and limited to certain time periods. This suggests that the capacity of Ethereum to serve as a hedge against inflation might vary, being more pronounced or limited under different circumstances. This highlights the necessity of considering wider economic and geopolitical contexts in evaluating Ethereum's effectiveness in relation to inflation or other financial assets. This approach acknowledges that Ethereum's performance as an inflation hedge is not static, but rather influenced by the prevailing economic environment and global events, as found by Phochanac et al. (2022) using a different methodology. This result could be attributed to the fact that Ethereum may be perceived not only as a crypto-currency but also as a decentralized platform that allows developers to create and deploy various applications using smart contracts, making it more vulnerable to shifting investor confidence in innovation. This may also be because Bitcoin has more established market presence and better long-term growth potential compared to Ethereum.

Fig. 4 illustrates strong negative (out-of-phase) dependencies between Bitcoin prices and financial instability, as measured by the U. S. Financial Stress Index (FSI), over several time-frequency domains: from 16 to 32 days between January 13, 2020, and May 7, 2020; from 32 to 128 days between July 23, 2019, and July 6, 2020;over 256 days between March 11, 2020, and April 21, 2021; and from 8 to 32 days between February 3, 2022, and July 27, 2022. The predominance of left-low-pointing arrows within the colored area of Fig. 4 indicates that, overall, FSI leads BTC. This result implies that when FSI increases, which means more financial instability, Bitcoin prices generally fall, which is in line with Zhang and Wang (2021). Interestingly, Bitcoin's value strongly depends on macro-factors and responds inversely to increased financial stress, suggesting its sensitivity to fluctuations in the overall financial system. Furthermore, the arrows pointing down on the left suggest that FSI precedes BTC, indicating a potential negative causal relationship in the specified time-frequency domains, which cover short to long term investment horizons (8–256 days). The macro-context associated with these specific time-frequency domains provides further insight into this result. This is because these domains encompass the U.S.-China trade war, which has increased financial stress due to global concerns and unfavorable news regarding trade negotiations (Huang et al., 2022; He et al., 2020; Di et al., 2019). They also coincide with the COVID-19 pandemic, which triggered a significant increase in

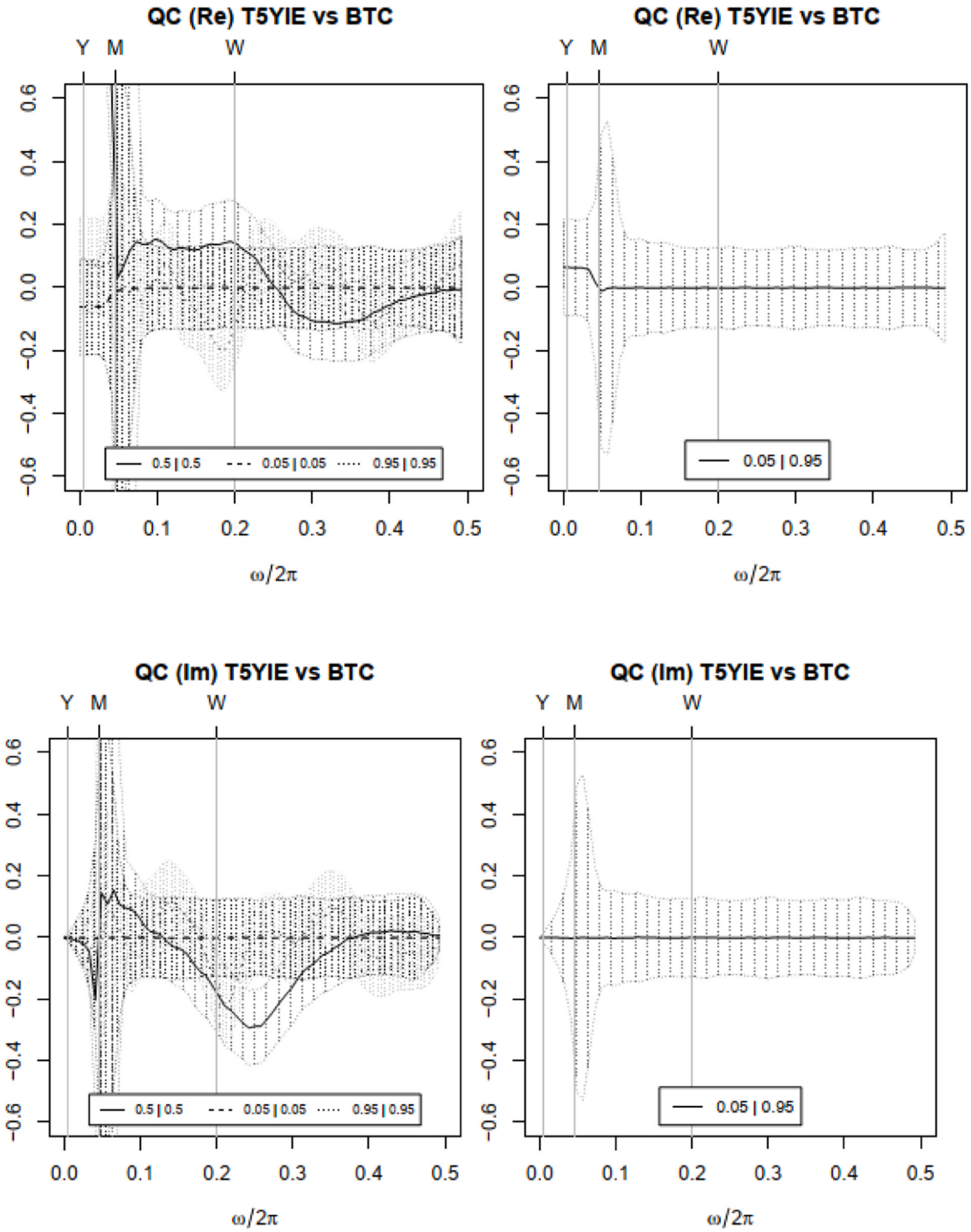

Fig. 6. Quantile coherency: T5YIE and BTC.

financial stress as global markets crashed and central banks lowered interest rates to near-zero levels and launched massive quantitative easing programs (Corbet et al., 2020). Finally, the time-frequency domains overlap with the war in Ukraine and the subsequent energy crisis, which could impact investor sentiment in the financial markets and exacerbate financial stress. These findings imply that

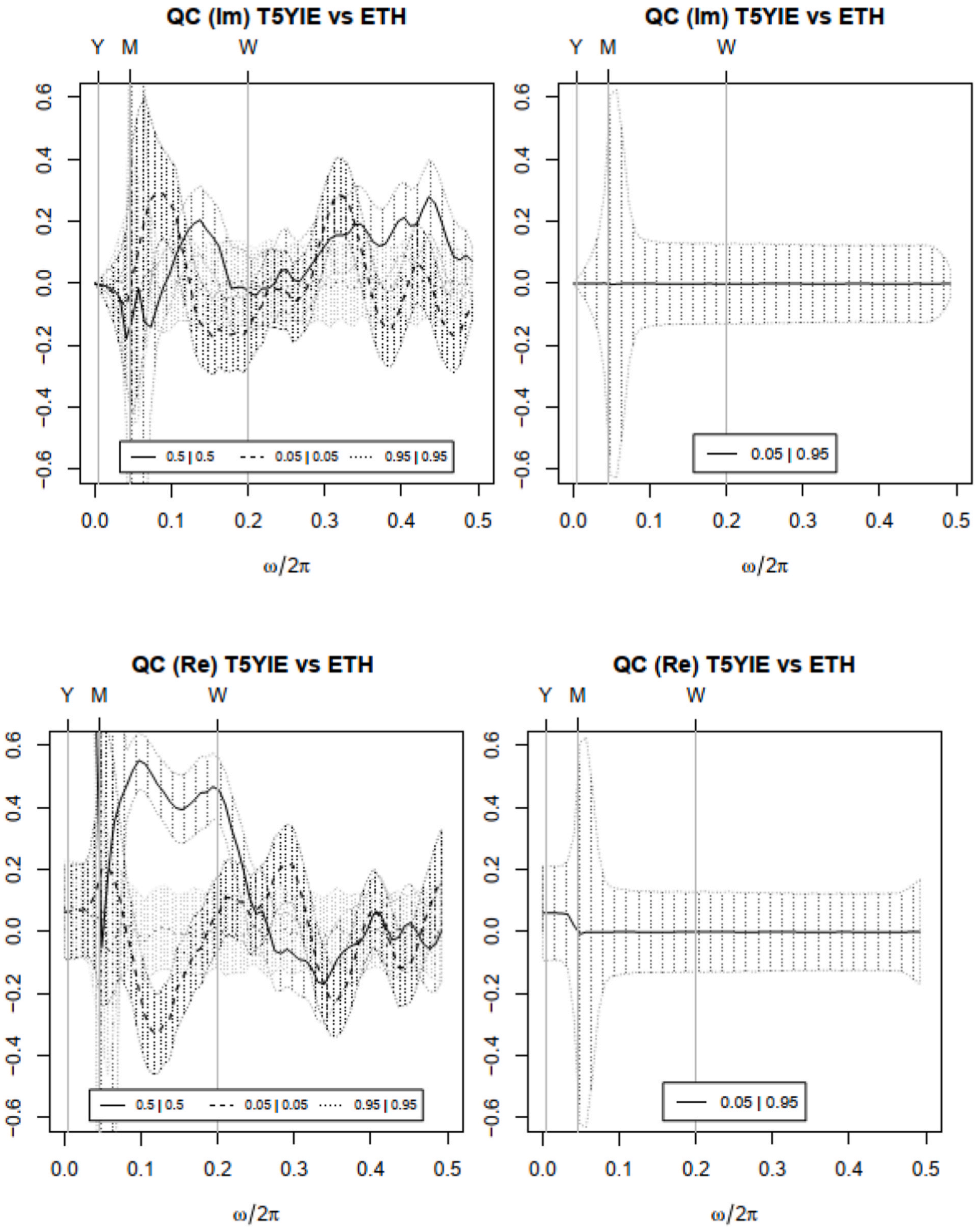

Fig. 7. Quantile coherency: T5YIE and ETH.

Bitcoin cannot serve as a hedge against financial instability during turbulent times, including not only financial turmoil, but also external disruptions in the real economy and the political sphere. Similar results were recently identified by Corbet et al. (2020), and (Khalfaoui et al., 2023) who used different empirical methods to examine the effects of the COVID-19 pandemic and the

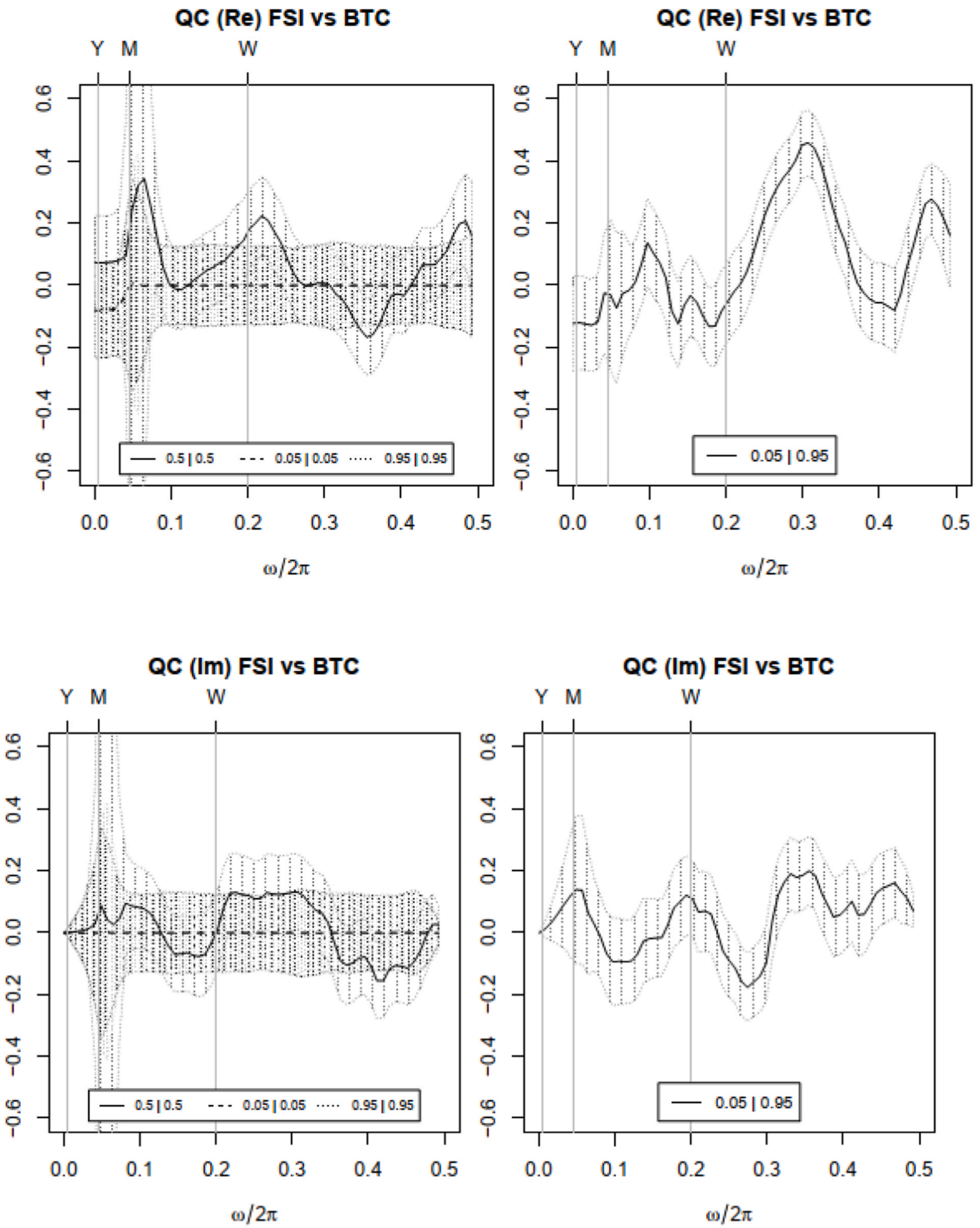

Fig. 8. Quantile coherency: FSI and BTC.

Russian-Ukrainian conflict on the relationship between traditional asset markets and the Bitcoin market. Their results generally indicate a contagion effect of uncertainty from the former market to the latter.

Fig. 5 displays strong negative dependencies between Ethereum prices and financial instability, suggesting that a cycle of increasing or decreasing financial stress corresponds to an inverse trend in Ethereum prices. The left-low-pointing arrows within the

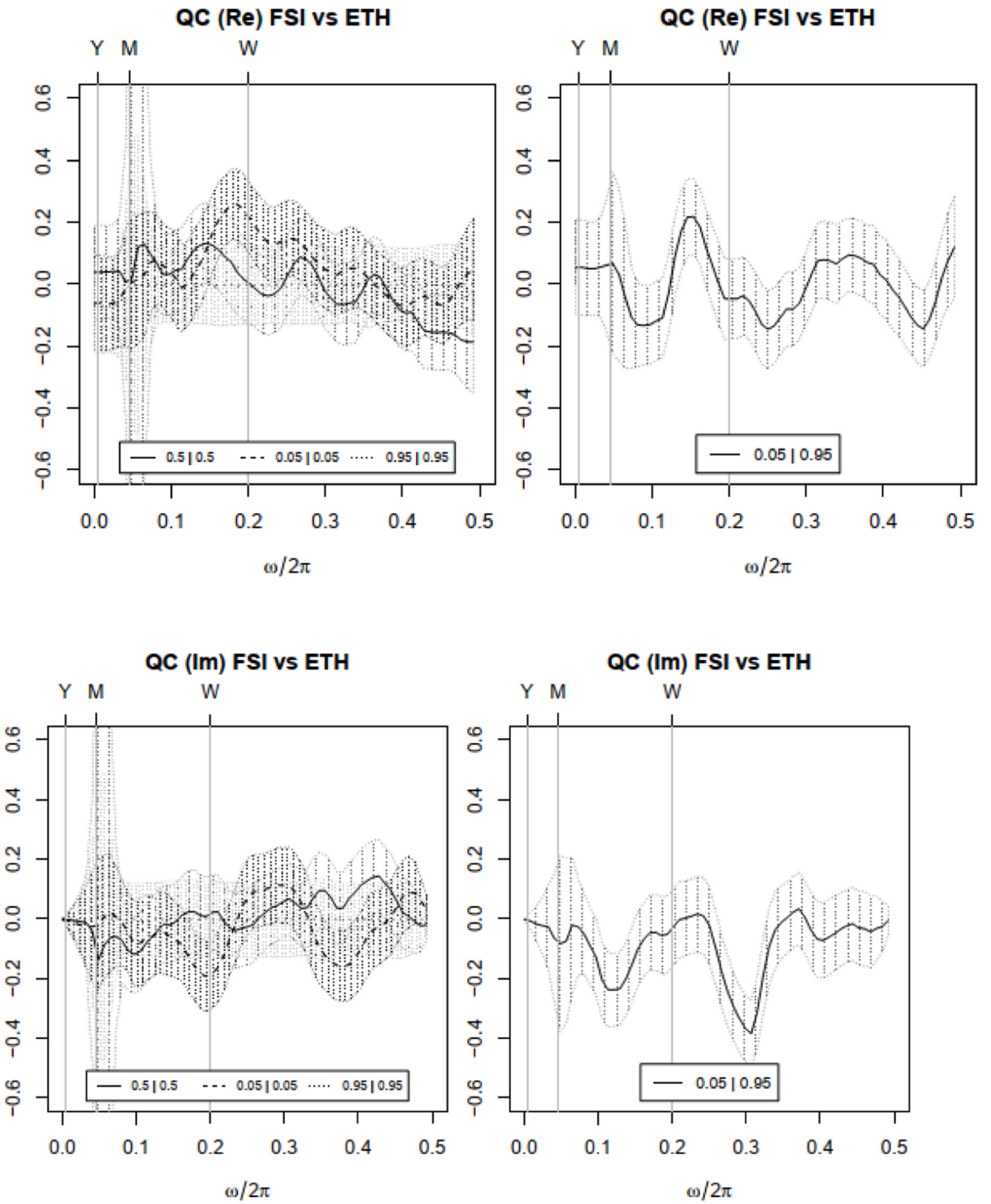

Fig. 9. Quantile coherency: FSI and ETH.

colored area indicate that changes in FSI occur before changes in Ethereum prices. This relationship is evident from September 18, 2019 to May 7, 2020 on the 16–64-day scale and from August 13, 2021 to May 31, 2022 on the 16–32-day scale. Thus, it appears that, like Bitcoin, the Ethereum market is susceptible to financial instability over short- to medium-term investment horizons in the event of financial turmoil and external disruptions in the real economy and political sphere, such as the U.S.-China trade war, the COVID-19 pandemic, the war in Ukraine, and the ensuing energy crisis. However, unlike Bitcoin, this vulnerability is not as prominent in the long run, which could be explained by a lower proportion of long-term Ethereum holders during these turbulent times. This lower prominence could be attributed to Bitcoin's more established presence in the market compared to Ethereum. This can be explained by the fact that Bitcoin has been around longer and has gained broader recognition as a digital store of value and a medium of exchange, while Ethereum, which is a newer crypto-currency, may not have established the same level of trust among investors.

4.2. Quantile coherency analysis

To further examine the time-frequency dependencies between Bitcoin (BTC), Ethereum (ETH), inflation (T5YIE), and financial instability (FSI), we employ the quantile coherency (QC) method proposed by Baruník and Kley (2019). This approach captures time-frequency dependencies across different quantiles of the joint distribution of variables, making it particularly useful for identifying extreme co-movements by focusing on the lowest, middle, and highest percentiles. In doing so, we can observe how the dependencies move from bearish to bullish market conditions in multiple time-frequency domains. Fig. 6 presents the results of the quantile consistency analysis. The top and bottom panels present the real (Re) and imaginary (Im) components of the quantile coherence estimates, respectively. The left panels present the quantile coherence estimates for the 5th percentile, 50th percentile, and 95th percentile of the joint distribution, revealing the time-frequency dependence combinations for the lower (0.05|0.05), middle (0.5| 0.5), and upper (0.95|0.95) quantiles, which encompass bearish, normal, and bullish market conditions. The right panels of the figures illustrate time-frequency dependencies between the lower and upper quantiles (0.05|0.95), describing the transmission dynamics from bearish to bullish market conditions. The x-axis represents the dependence between quantiles of the joint distribution along weekly (W), monthly (M) and annual (Y) cycles. The dotted areas in the panels indicate the 95 % confidence intervals for statistical significance.

In Fig. 6, the left panels illustrate that the dependencies between Bitcoin prices and expected inflation are more pronounced under normal and bullish market conditions, while hovering around zero under bearish market conditions. This suggests that Bitcoin's value might be seen as a hedge against inflation when the market is stable or on an upward trend. Such evidence corroborates the results reported by Matkovskyy and Jalan (2020) who reveal that Bitcoin could hedge against inflation in the UK and Japan. However, in bearish conditions, these dependencies are minimal, indicating that during market downturns, Bitcoin's correlation with expected inflation weakens. Furthermore, these dependencies become stronger as they occur in medium and long-term frequencies. This could mean that Bitcoin's reaction to changes in inflation expectations becomes more pronounced over longer periods, indicating a potential long-term hedging characteristic of Bitcoin against inflation (over one business year).However, the right panels of the figure do not show a significant transmission effect of these dependencies between bearish and bullish market states. This implies that the correlation between Bitcoin prices and expected inflation doesn't transition significantly from bearish to bullish markets, suggesting a possible lack of consistent hedging capability across transitional market states.

The left panels in Fig. 7 reveal significant dependencies between Ethereum prices and anticipated inflation in all market conditions, especially in the medium-term frequencies (over one business month). As the frequency extends to the long term, the dependencies tend to decrease. Similar to the trend observed for Bitcoin prices, no significant transmission dynamics are revealed between bearish and bullish market conditions. This suggests that Ethereum, unlike Bitcoin, maintains a more constant correlation with expected inflation regardless of market state. However, Ethereum's correlation with expected inflation might diminish over longer periods. Ethereum is not just a cryptocurrency but also a platform for decentralized applications, which could make it more resilient to market downturns. However, the fact that these dependencies decrease in the long-term frequencies suggests that, over longer periods, other factors might become more dominant in influencing Ethereum's price, such as the performance of innovation sectors.

In Fig. 8, the left panels reveal strong dependencies between financial stability and Bitcoin prices under normal and bullish market conditions across nearly all frequencies. This finding confirms the link between Bitcoin prices and financial instability which suggests that the effects of financial and crypto-currency bumps can persist over long periods of time. However, these dependencies tend toward zero during bearish market conditions. The right-hand side of the figure shows a strong transmission effect of these dependencies when moving from a bullish market to a bearish market, with this effect being especially noticeable at short-term frequencies (one business week). This could indicate that during rapid transitions between bullish and bearish markets, the price of Bitcoin can become more reactive to changes in financial instability. As for the relationships between Ethereum prices and financial instability, the left-hand side of Fig. 9 demonstrates significant dependencies under all market conditions. This suggests that Ethereum's price could be more sensitive to changes in financial stability than Bitcoin's under bearish market conditions. This observed behavior may be linked to Ethereum's inherently riskier nature compared to Bitcoin (Ghorbel and Jeribi, 2021; Beneki et al., 2019). Ethereum, often perceived as a more dynamic and risk-prone asset, tends to react more intensely to unfavorable economic circumstances in contrast to Bitcoin. In times of market skepticism and financial instability, investors typically exhibit heightened risk aversion. Consequently, Ethereum, due to its perceived higher risk, might experience a more marked effect on its price relative to Bitcoin.

The figure indicates a particular strength of these dependencies in the medium-term frequencies (over one business month). The figure's right-hand side reveals a significant transmission effect of these dependencies when transitioning from bullish to bearish market states, particularly evident at short- and medium-term frequencies (one business week and one business month). As with the Bitcoin price, this result shows that during market transitions, the Ethereum price can become more responsive to changes in financial instability.

5. Conclusion

This study investigates the resilience of Bitcoin and Ethereum amid financial instability and inflation, taking into account significant recent macro-disturbances in the economy and political landscape. These disturbances include the U.S.-China trade war, the COVID-19 pandemic, the Ukraine conflict, and the subsequent energy crisis. Employing wavelet coherence analysis and the novel quantile coherency method (Baruník and Kley, 2019), we capture the time-frequency dependencies between Bitcoin and Ethereum prices, the U.S. 5-year inflation rate (utilized as a proxy for expected inflation), and the U.S. Financial Stress Index (FSI, a measure of financial instability). We base our study on a daily data compilation that spans 1261 business days, from April 16, 2018, through to April 14, 2023.

Our findings suggest that, during periods of the contemptuous turmoil, crypto-currency investors are adjusting their Bitcoin holdings based on changing inflation expectations. These strategic moves precipitate a rise in Bitcoin prices, a trend that is noticeable over both short-term (16–32 days) and long-term (64–128 days) investment horizons. However, this role as a hedge against inflation is minimal in bearish market conditions. Moreover, Bitcoin cannot function as a reliable hedge against financial instability, especially in rapid transitions between bullish and bearish market conditions. We also observe a divergent relationship between inflation expectations and the prices of Ethereum and Bitcoin. Both cryptocurrencies display positive correlations with inflation expectations during the COVID-19 crisis, yet the association between inflation expectations and Ethereum prices seems confined to short and medium-term (16–64 days) frequencies regardless of market state. Moreover, the absence of a well-defined correlation between inflation expectations and Ethereum prices during the post-COVID-19 recovery, the conflict in Ukraine, and the ensuing energy crisis implies that Ethereum's capacity to serve as a hedge against inflation expectations may be contingent on specific contexts and temporal periods. In addition, as with Bitcoin, the Ethereum market shows a high degree of exposure to financial instability over short and medium investment periods in times of turmoil. However, unlike Bitcoin, this vulnerability does not persist as strongly over the long term and it particularly shows increased sensitivity in bearish market conditions, compared to the price of Bitcoin.

In concluding this study, it is crucial to critically evaluate the methodological limitations inherent in our analytical approach. Wavelet coherence, though a valuable tool for analyzing time series, encounters two main challenges. Firstly, its sensitivity to the choice of the mother wavelet and parameters can significantly influence coherence patterns and the quality of the results, as noted by Maheswaran and Khosa (2012) and Rhif et al. (2019). Secondly, the presence of edge effects can lead to misleading artifacts, introducing an additional layer of complexity to the interpretation of results, particularly when dealing with limited data, as discussed by Tomás et al. (2016). These challenges underscore the importance of a careful methodology and necessary adjustments when applying wavelet coherence in time series analyses. In our study, we have meticulously selected a wavelet that aligns harmoniously with the unique characteristics of our time series data. Similarly, quantile coherence, another critical tool for time series analysis, is not without its limitations. Its effectiveness is contingent on the assumption of data stationarity, as highlighted by Baruník and Kley (2019), and may encounter challenges in the presence of significant non-stationarity. Additionally, this method is inherently limited to bivariate analyses, thereby constraining its applicability to situations involving only two variables. However, while these limitations are acknowledged, they do not detract from the relevance of our study, as our investigation is specifically focused on a targeted examination of two time series that exhibit stationarity.

6. Implications

Findings of this study carry out significant implications for policymakers and Investors especially during periods of turbulence and high inflation. Investors should strategically adjust their Bitcoin and Ethereum holdings in response to inflation expectations during turbulent periods. Further, portfolio managers shall to consider Bitcoin and Ethereum as a dynamic asset within portfolios and taken into consideration its sensitivity to inflation pressure and economy financial instability. The study underscores the need for caution, particularly in bearish market conditions, where Bitcoin's and Ethereum's efficacy as an inflation hedge diminishes, and its reliability against financial instability is questionable. The study underscores the need for caution, particularly in bearish market conditions, where Bitcoin's/Ethereum effectiveness against inflation and financial instability decrease considerably. This suggests that investors should adopt diversified risk management strategies during economic downturns. Specifically, during market downturns, where traditional investments may face challenges, relying solely on Bitcoin and/or Ethereum as an inflation hedge becomes less effective and its reliability in mitigating financial instability is doubtful. In this spirit, investors are advised to adopt a diversified risk management strategy, suggesting spreading investments across various asset classes, including precious metals. Thus, by diversifying their investments, investors can create a more resilient portfolio to inflationary pressure and financial uncertainties during economic downturns.

Policymakers should recognize the sensitivity of Bitcoin and Ethereum to inflation pressure and financial instability. This implies the need for an enhanced systemic risk assessment framework that incorporates the dynamics of these cryptocurrencies. Thus, understanding the behavior of cryptocurrencies can contribute to a more accurate evaluation of potential risks to the financial system. Moreover, policy makers are invited to establish effective measures to enhance market stability, prevent excessive speculation, or protect investors during heightened financial stress. Furthermore, policymakers should consider the reactions of Bitcoin and Ethereum to inflation and financial stress as an additional signal when assessing inflation expectations and systemic risk to plan efficient monetary policy actions.

The findings of this study have significant implications for both policymakers and investors, especially during periods of turbulence and high inflation. Investors are advised to strategically adjust their holdings in Bitcoin and Ethereum in response to inflation expectations. Portfolio managers should view Bitcoin and Ethereum as dynamic assets within portfolios, considering their sensitivity to inflationary pressure and financial instability. The research highlights the importance of caution, particularly in bearish market conditions, where the effectiveness of Bitcoin and Ethereum as inflation hedges diminishes, and their reliability against financial instability becomes uncertain. This suggests that investors should employ diversified risk management strategies during economic downturns. In market downturns, where traditional investments may falter, relying solely on Bitcoin and/or Ethereum as an inflation hedge is less effective. Therefore, adopting a diversified approach to risk management, including spreading investments across various asset classes like precious metals, is recommended to create a more resilient portfolio against inflationary pressures and financial instability.

For policymakers, recognizing the sensitivity of Bitcoin and Ethereum to inflationary pressures and financial instability is crucial. This calls for an enhanced systemic risk assessment framework that takes into account the dynamics of these cryptocurrencies. A deeper understanding of cryptocurrency behavior can contribute to a more accurate evaluation of potential risks to the financial system. Policymakers are also encouraged to implement effective local and global regulations to enhance the crypto-market stability, curb excessive crypto-speculation, and protect crypto-investors, especially during periods of heightened financial stress and inflation rates. Additionally, policymakers should consider the reactions of Bitcoin and Ethereum to inflation and financial stress as vital indicators when assessing inflation expectations and systemic risks to formulate efficient monetary policy actions.

CRediT authorship contribution statement

Jean-Michel Sahut: Conceptualization, Writing – review & editing. **Nadia Arfaoui:** Conceptualization, Methodology, Software, Writing – original draft. **Najeh Chaâbane:** Data curation, Writing – original draft. **Brahim Gaies:** Conceptualization, Investigation, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

Abbassi, W., Kumari, V., Pandey, D.K., 2023. What makes firms vulnerable to the Russia-Ukraine crisis? J. Risk Financ. 24 (1), 24–39.

Aguiar-Conraria, L., & Soares, M.J. (2011). The continuous wavelet transform: A primer (No. 16/2011). NIPE-Universidade do Minho.

Akhtaruzzaman, M., Boubaker, S., Sensoy, A., 2021. Financial contagion during COVID-19 crisis. Financ. Res. Lett. 38, 101604.

Akhtaruzzaman, M., Boubaker, S., Umar, Z., 2022. COVID-19 media coverage and ESG leader indices. Financ. Res. Lett. 45, 102170.

Akhtaruzzaman, M., Boubaker, S., & Goodell, J.W. (2023). Did the collapse of Silicon Valley Bank catalyze financial contagion?

Aloui, D., Gaies, B., Hchaichi, R., 2023. Exploring environmental degradation spillovers in Sub-Saharan Africa: the energy–financial instability nexus. Econ. Change Restruct. 1–26.

Ammous, S., 2018. Can cryptocurrencies fulfil the functions of money? Q. Rev. Econ. Financ. 70, 38–51.

Angelis, J., Da Silva, E.R., 2019. Blockchain adoption: a value driver perspective. 19. Bus. Horiz. 62 (3), 307–314.

Baruník, J., Kley, T., 2019. Quantile coherency: A general measure for dependence between cyclical economic variables. Econ. J. 22 (2), 131–152.

Baur, D.G., Dimpfl, Th, 2021. The volatility of Bitcoin and its role as a medium of exchange and a store of value. Empir. Econ. 61, 2663–2683.

Beneki, ch, Koulis, A., Kyriazis, N., Papadamou, S., 2019. Investigating volatility transmission and hedging properties between Bitcoin and Ethereum. Res. Int. Bus. Financ. 48, 219–227.

Blau, B.M., Griffith, T., Whibty, R., 2021. Inflation and Bitcoin: a descriptive time-series analysis. Econ. Lett. 203, 109848.

Bodie, Z., 1976. Common stocks as a hedge against inflation. J. Financ. 31 (2), 459–470.

Boubaker, S., Goodell, J.W., Pandey, D.K., Kumari, V., 2022. Heterogeneous impacts of wars on global equity markets: evidence from the invasion of Ukraine. Financ. Res. Lett. 48.

Boubaker, S., Goodell, J.W., Kumar, S., Sureka, R., 2023. COVID-19 and finance scholarship: a systematic and bibliometric analysis. Int. Rev. Financ. Anal. 85, 102458.

Bouri, E., Molnar, P., Azzi, G., Roubaud, D., Hagfors, L.I., 2017. On the hedge and safe haven properties of Bitcoin: is it really more than a diversifier? Financ. Res. Lett. 48, 2019.

Bouri, E., Rangan, G., Marco Lau, Ch.K., Roubaud, D., Wang, Sh, 2018. Bitcoin and global financial stress: a copula-based approach to dependence and causality in the quantiles. Q. Rev. Econ. Financ. 69, 297–307.

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. Q. Rev. Econ. Financ. 77, 156–164.

Cagan, P. (1974). Inflation and market structure 1967-1973. NBER Working Paper.

Charfeddine, L., Benlagha, Maouchi, Y., 2020. Investigating the dynamic relationship between cryptocurrencies and conventional assets: implications for financial investors. Econ. Model. 85, 198–217.

Chen, C., Liu, L., Zhao, N., 2020. Fear sentiment, uncertainty, and bitcoin price dynamics: the case of COVID-19. Emerg. Mark. Financ. Trade 56 (10), 2298–2309.

Chen, J., Huang, Y., Ren, X., Qu, J., 2022. Time-varying spillovers between trade policy uncertainty and precious metal markets: evidence from China-US trade conflict. Resour. Policy 76.

Choi, S., Shin, J., 2022. Bitcoin: an inflation hedge but not a safe haven. Financ. Res. Lett. 46, 102379.

Chortane, S.G., Pandey, D.K., 2022. Does the Russia-Ukraine war lead to currency asymmetries? A US dollar tale. J. Econ. Asymm. 26.

Ciaian, P., Rajcaniova, M., Kancs, A., 2015. The economics of BitCoin price formation. Appl. Econ. 1799–1815.

Conlon, Th, Corbet, Sh, McGee, R., 2021. Inflation and cryptocurrencies revisited: a time-scale analysis. Econ. Lett. 206, 109996.

Corbet, S., Goodell, J.W., Günay, S., 2020. Co-movements and spillovers of oil and renewable firms under extreme conditions: New evidence from negative WTI prices during COVID-19. Energy Econ. 92.
Corbet, Sh, Meegan, A., Larkin, Ch, Lucey, B., Yarovaya, L., 2018. Exploring the dynamic relationships between cryptocurrencies and other financial assets. Econ. Lett. 165, 28–34.
Di, D., Luft, G., Zhong, D., 2019. Why did Trump launch a trade war? A political economy explanation from the perspective of financial constraints. Econ. Political Stud. 7 (2).
Fama, E.F., Schwert, G.W., 1977. Asset returns and inflation. J. Financ. Econ. 5 (2), 115–146.
Feng, W., Wang, Y., Zhang, Z., 2018. Can cryptocurrencies be a safe haven: a tail risk perspective analysis. Appl. Econ. 50, 4745–4762.
Gaies, B., 2022. Reassessing the impact of health expenditure on income growth in the face of the global sanitary crisis: the case of developing countries. Eur. J. Health Econ. 23 (9), 1415–1436.
Gaies, B., & Chaâbane, N. (2023). The dance of dependence: a macro-perspective on financial instability and its complex influence on the Euro-American green markets. Journal of Economic Studies.
Gaies, B., Chaâbane, N., Bouzouita, N., 2024. Navigating the storm: Time-frequency quantile dependence and non-linear causality between crypto-currency market volatility and financial instability. Q. Rev. Econ. Financ. 93, 43–70.
Gaies, B., Nakhli, M.S., Sahut, J.M., Guesmi, K., 2021. Is Bitcoin rooted in confidence?–Unraveling the determinants of globalized digital currencies. Technol. Forecast. Soc. Change 172, 121038.
Gaies, B., Nakhli, M.S., Ayadi, R., Sahut, J.M., 2022. Causal links between investor sentiment and financial instability: new evidence from a bootstrap rolling window approach. J. Econ. Behav. Organ. 290–303.
Gaies, B., Nakhli, M.S., Sahut, J.M., Schweizer, D., 2023. Interactions between investors' fear and greed sentiment and Bitcoin prices. North Am. J. Econ. Financ. 67, 101924.
Ghorbel, A., Jeribi, A., 2021. Investigating the relationship between volatilities of cryptocurrencies and other financial assets. Decis. Econ. Financ. 44, 817–843.
Gök, R., Bouri, E., Gemici, E., 2022. Can Twitter-based economic uncertainty predict safe-haven assets under all market conditions and investment horizons? Technol. Forecast. Soc. Change 185, 122091.
Goodell, J.W., Huynh, T.L.D., 2020. Did Congress trade ahead? Considering the reaction of US industries to COVID-19. Financ. Res. Lett. 36, 101578.
Grinberg, R., 2012. Bitcoin: an innovative alternative digital currency. UC Law Sci. Technol. J. 4 (1).
Guesmi, K., Saadi, S., Abid, I., Ftiti, Z., 2019. Portfolio diversification with virtual currency: Evidence from bitcoin. Int. Rev. Financ. Anal. 63, 431–437.
He, F., Lucey, B., & Wang, Z. (2020). Trade policy uncertainty and its impact on the stock market -evidence from China-US trade conflict. Finance Research Letters.
Hoque, ME., Low, S-W., 2022. Reactions of bitcoin and gold to categorical financial stress: New evidence from quantile estimation. Risks 10 (7), 136. https://doi.org/10.3390/risks10070136.
Hu, J., Chen, Z., 2016. A unit root test against globally stationary ESTAR models when local condition is non-stationary. Econ. lett. 146, 89–94.
Huang, Y.-S., Lu, Y.-X., Tang, N., 2022. World prospers China: Chinese private firms with lending before the China-United States trade war. Appl. Econ. Lett. 29 (10), 920–926.
Hudson, R., Urquhart, A., 2019. Technical trading and cryptocurrencies. Ann. Oper. Res. 297, 191–220.
Huynth, T.L.D., Nasir, M.A., VO, X.V., Nguyen, T.T., 2020. Small things matter most": The spillover effects in the cryptocurrency market and gold as a silver bullet. North Am. J. Econ. Financ. 54, 101277.
Jin, Ch, Tian, X., 2024. Enhanced safe-haven status of Bitcoin: evidence from the Silicon Valley Bank collapse. Financ. Res. Lett. 59, 104689.
Kang, S.H., Yoon, S.M., Bekiros, S., 2020. Bitcoin as hedge or safe haven: evidence from stock, currency, bond and derivatives markets. Comput. Econ. 56, 529–545.
Kanzari, D., Nakhli, M.S., Gaies, B., Sahut, J.M., 2023. Predicting macro-financial instability–How relevant is sentiment? Evidence from long short-term memory networks. Res. Int. Bus. Financ. 65, 101912.
Khalfaoui, R., Mefteh-Wali, S., Dogan, B., Ghosh, S., 2023. Extreme spillover effect of COVID-19 pandemic-related news and cryptocurrencies on green bond markets: A quantile connectedness analysis. Int. Rev. Financ. Anal. 86, 102496 https://doi.org/10.1016/j.irfa.2023.102496.
Klein, T., Thu, H.Ph, Walther, Th, 2018. Bitcoin is not the New Gold – a comparison of volatility, correlation, and portfolio performance. Int. Rev. Financ. Anal. 59, 105–116.
Kruse, R., 2011. A new unit root test against ESTAR-based on a class of modified statistics. Stat. Pap. 52, 71–85. https://doi.org/10.1007/s00362-009-0204-1.
Kumar, A.S., Padakandla, S.R., 2022. Testing the safe-haven properties of gold and bitcoin in the backdrop of COVID-19: a wavelet quantile correlation approach. Financ. Res. Lett. 47, 102707.
Kumari, V., Kumar, G., Pandey, D.K., 2023. Are the European Union stock markets vulnerable to the Russia-Ukraine war? J. Behav. Exp. Financ. 37, 100793.
Liu, Z., Dai, P., Huynh, T.L.D., Zhang, T., & Zhang, G. (2022). Industries' heterogeneous reactions during the COVID-19 outbreak: Evidence from Chinese stock markets. Journal of International Financial Management & Accounting.
Maheswaran, R., Khosa, R., 2012. Comparative study of different wavelets for hydrologic forecasting. Comput. Geosci. 46, 284–295.
Matkovsky, R., Jalan, A., 2021. Bitcoin vs Inflation: Can Bitcoin Be a Macro Hedge? Evidence From a Quantile-on-Quantile Model. Rev. écon. 72 (5), 785–798.
Matkovskyy, R., Jalan, A., Dowling, M., 2020. Effects of economic policy uncertainty shocks on the interdependence between Bitcoin and traditional financial markets. Q. Rev. Econ. Financ. 77, 150–155.
Meshcheryakov, A., Ivanov, S., 2020. Ethereum as a hedge: The intraday analysis. Econ. Bull. 40, 101–108.
Meynkhard, A., 2020. Fair market value of bitcoin: halving effect. Manag. Financ. Innov. 16 (4), 72–85.
Naeem, M.A., Arfaoui, N., 2023. Exploring downside risk dependence across energy markets: Electricity, conventional energy, carbon, and clean energy during episodes of market crises. Energy Econ. 127, 107082.
Ozcelebi, O., 2020. Assessing the impacts of financial stress index of developed countries on the exchange market pressure index of emerging countries. Int. Rev. Econ. Financ. 70, 288–302.
Pandey, D.K., Kumari, V., 2021. Event study on the reaction of the developed and emerging stock markets to the 2019-nCoV outbreak. Int. Rev. Econ. Financ. 71, 467–483.
Pandey, D.K., Lucey, B.M., Kumar, S., 2023a. Border Disputes, Conflicts, War, and Financial Markets Research: A Systematic Review. Res. Int. Bus. Financ., 101972
Pandey, D.K., Assaf, R., Rai, V.K., 2023c. Did the Indian stock market sail the Russia-Ukraine storm safely? J. Econ. Asymmet. 28, e00319.
Pandey, D.K., Hassan, M.K., Kumari, V., Hasan, R., 2023b. Repercussions of the Silicon Valley Bank collapse on global stock markets. Financ. Res. Lett., 104013
Paule-Vianez, J, Prado-Román, Camilo, Gómez-Martínez, Raúl, 2020. Economic policy uncertainty and Bitcoin. Is Bitcoin a safe-haven asset? Eur. J. Manag. Bus. Econ. 29 (3), 347–363.
Phochanac, P., Pirabun, N., Leurcharusmee, S., Yamaka, W., 2022. Do Bitcoin and traditional financial assets act as an inflation hedge during stable and turbulent markets? Evidence from high cryptocurrency adoption countries. Axioms 11 (7), 339.
Rhif, M., Ben Abbes, A., Farah, I.R., Martínez, B., Sang, Y., 2019. Wavelet transform application for/in non-stationary time-series analysis: a review. Appl. Sci. 9 (7), 1345.
Sakurai, Y., Kurosaki, T., 2023. Have cryptocurrencies become an inflation hedge after the reopening of the U.S. economy? Res. Int. Bus. Financ. 65, 101915.
Selmi, R., Mensi, W., Hammoudeh, S., Bouoiyour, J., 2018. GIs Bitcoin a hedge, a safe haven or a diversifier for oil price movements? A comparison with gold. Energy Econ. 74, 787–801.
Shi, Y., Tiwari, A.K., Gozgor, G., Lu, Z., 2020. Correlations among cryptocurrencies: Evidence from multivariate factor stochastic volatility model. Res. Int. Bus. Financ. 53, 101231.
Smales, L.A., 2019. Bitcoin as a safe haven: Is it even worth considering? Financ. Res. Lett. 30, 385–393.
Smales, L.A. (2022). Cryptocurrency as an Alternative Inflation Hedge? Acconting and Finance.
Tomás, R., Li, Z., Lopez-Sanchez, J.M., Liu, P., Singleton, A., 2016. Using wavelet tools to analyse seasonal variations from InSAR time-series data: a case study of the Huangtupo landslide. Landslides 13, 437–450.

Umar, M., Su, Ch.W., Rizvi, S.K.A., Shao, X.F., 2021. Bitcoin: a safe haven asset and a winner amid political and economic uncertainties in the US? Technol. Forecast. Soc. Change 167, 120680.
Umar, Z., Polat, O., Choi, S.Y., Teplova, T., 2022. The impact of the Russia-Ukraine conflict on the connectedness of financial markets. Financ. Res. Lett. 48, 102976.
Urquhart, A., Zhang, H., 2019. Is Bitcoin a hedge or safe haven for currencies? An intraday analysis. Int. Rev. Financ. Anal. 63, 49–57.
Wen, F., Tong, X., Ren, X., 2022. Gold or Bitcoin, which is the safe haven during the COVID-19 pandemic? Int. Rev. Financ. Anal. 81, 102121.
Yarovaya, L., Matkovskyy, R., Jalan, A., 2022. The COVID-19 black swan crisis: reaction and recovery of various financial markets. Res. Int. Bus. Financ. 59, 101521.
Zhang, H., Wang, P., 2021. Does Bitcoin or gold react to financial stress alike? Evidence from the U.S. and China. Int. Rev. Econ. Financ. 71, 629–648.