IJEEP
INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY
EconJournals
ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2025, 15(3), 411-425.

EconJournals

Connectedness between Bitcoin, Gold, Gold-Backed Cryptocurrencies and Energy Commodities during the COVID-19 Pandemic and the Russia-Ukraine Conflict

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Received: 22 November 2024 **Accepted:** 24 March 2025 **DOI:** https://doi.org/10.32479/ijeep.18500

ABSTRACT

This paper explores the interconnectedness and spillover relationships among Bitcoin, gold, gold-backed cryptocurrencies, and energy commodities during the COVID-19 pandemic and the Russia-Ukraine military conflict. Using a quantile connectedness approach, we reveal diverse influence dynamics among digital assets, with Gold, DGX, and PAXG emerging as key contributors to the network's total connectedness. Notably, the cTCI/TCI ratio underscores substantial direct linkages, emphasizing significant interconnections among digital assets. DGX acts as a principal information transmitter, while gas plays a crucial role as a primary receiver, suggesting its potential as a diversifier. The time-quantile analysis highlights heightened connectedness during significant events, providing valuable insights for investors and risk managers. Results underscore varying roles of assets, with PAXG persistently acting as a net transmitter and Bitcoin and Gold displaying nuanced patterns. Interestingly, Gold demonstrated certain safe haven characteristics only during the Russia-Ukraine war. The time-frequency analysis at the median quantile emphasizes the dominance of short-term dynamics, prompting the need for adaptive risk management strategies. Overall, this study facilitates a nuanced understanding of market dynamics, offering practical insights for different periods.

Keywords: Connectedness, Spillover, Bitcoin, Gold, Gold-Backed Cryptocurrencies, COVID-19, Russia-Ukraine War
JEL Classifications: G01, G10, C32, Q02

1. INTRODUCTION

Since its initial identification in Wuhan, China, in December 2019, the COVID-19 pandemic has persisted for over 2 years, exerting adverse impacts on nearly every industry globally, encompassing energy markets as well. Precisely, this health crisis has resulted in a decline in global prices of energy commodities (Albulescu, 2020; Bakas and Triantafyllou, 2020; Mokni et al., 2021; Umar et al., 2021; Iqbal et al., 2023).

The oil markets have faced the most substantial impact, attributed to the decline in travel resulting from mitigation measures (Ahmed et al., 2021). For instance, at the end of March 2020, the cost of Brent crude per barrel declined to around \$23. This value represents the lowest point since November 2002 (Dutta et al., 2020). Meanwhile, the price of US West Texas Intermediate (WTI) fell below \$20/barrel, reaching the lowest point in 18 years (Dutta et al., 2020). As reported by Corbet et al. (2020a), the WTI crude oil price continued its downward trend on April 20, 2020. Gil-Alana and Monge (2020) discovered that the crude oil market became inefficient during the COVID-19 crisis. Devpura and Narayan (2020) stated that there was an escalation in oil price instability after the onset of the COVID-19 pandemic. Huang and Zheng (2020) stated that the significant decline in demand for crude oil during the COVID-19 outbreak led to a negative price for WTI crude oil. Zhang and Hamori (2021) also found that the consequences of COVID-19 generated an unparalleled degree of risk, causing a drastic decline in oil prices.

Moreover, natural gas prices have been notably influenced by the COVID-19 pandemic, causing variations and shifts in the market. The onset of the pandemic led to a considerable drop in the demand for natural gas, prompted by decreased economic activity and travel limitations (Cieślik et al., 2022). Kumar et al. (2022) discovered a global shock in the gas market during this health crisis as a result of a reduction in gas demand and supply. Norouzi (2021) demonstrates that the oil and gas industry is significantly affected by the repercussions of COVID-19. Iyke (2020) also stated that the COVID-19 pandemic explains 27% of the return volatility in gas and oil markets.

While the COVID-19 situation persists, the world witnessed a significant black swan occurrence: the Russian-Ukrainian military conflict on February 24, 2022. This incident has had repercussions and created significant uncertainty around the globe (Berninger et al., 2022; Bossman et al., 2022; Boungou and Yatié, 2022; Boubaker et al., 2022; Karkowska and Urjasz, 2023). The conflict has emerged as a widely discussed subject, significantly impacting the global economy, particularly within the international crude oil and gas market (Chen et al., 2023). In fact, these energy commodity markets have been extensively influenced and have seen significant changes in supply and prices (Liadze et al., 2022). For instance, the prices of Brent and West Texas Intermediate (WTI) crude oil rose to exceed 100 US Dollars per barrel on the day of the assault. Oil has also shifted from a net recipient to a net producer of spillovers during this crisis (Adekoya et al., 2022). This assault has indeed impacted gas prices, causing them to rise to approximately 4 US Dollars per gallon (Liadze et al., 2022).

Across various quantiles, Chishti et al. (2023) discovered that the conflict between Russia and Ukraine significantly worsens conditions in the crude and Brent oil markets. Wang et al. (2022) stated that commodities' roles in return and implied volatility regimes have shifted. Their results revealed that crude oil has become the net producer of volatility spillovers. Fang and Shao (2022) examine the effects of the Russia-Ukraine conflict on the vulnerability to market instability within commodity markets. Their empirical results reveal a significant increase in the levels of volatility in energy markets following the escalation of the Russia-Ukraine conflict. Saad (2023) employs a combination of the event study methodology and models from the GARCH family to scrutinize the impact of the Russia-Ukraine conflict on returns and volatility within the natural gas futures market in the United States. This inquiry exposes that natural gas futures prices displayed a negative reaction in response to the Russia-Ukraine war.

The fluctuations observed in oil and gas prices during the COVID-19 pandemic and the Russia-Ukraine conflict have increased the likelihood of tail risks in oil and gas assets. This suggests that investments in these markets become more precarious and could result in more pronounced losses. Hence, it is crucial to pinpoint an alternative investment tool to mitigate the risks associated with oil and gas.

While associations among the majority of asset classes experienced a noteworthy rise, gold was the only asset to register an uptick in value during the year 2020. In fact, various research studies explore whether gold serves as a safe-haven asset during periods of turbulence (Baur and Lucey, 2010; Baur and McDermott, 2010; Reboredo, 2013; Ciner et al., 2013; Shahzad et al., 2020; Adekoya et al., 2021). Throughout history, this precious metal has been considered both a means of diversification and a hedge during periods of economic stability. It is also perceived as a refuge during crises and turbulent market conditions (Baur and Lucey, 2010; Baur and McDermott, 2010). Another segment of recent academic literature has focused on investigating the safe haven characteristics of Bitcoin. The latter represents a well-known asset for diversification, hedging, and seeking safety (Bouri et al., 2017a; Bouri et al., 2020; Frikha et al., 2023). Nevertheless, Bitcoin's effectiveness is significantly curtailed by its price volatility (Jeribi and Snene-Manzli, 2020; Cheema et al., 2020; Fakhfekh and Jeribi, 2020; Corbet et al., 2020a; Jeribi and Masmoudi, 2021).

Moreover, significant focus has been dedicated to exploring the capabilities of alternative types of cryptocurrencies in comparison to traditional assets, exemplified by stablecoins. These digital currencies derive their value from assets that are relatively stable, such as precious metals and the U.S. dollar. They were established as a more flexible alternative to fiat currencies for cryptocurrency exchanges, and they are becoming a more substantial part of the cryptocurrency industry and alternative finance.

Gold-backed cryptocurrencies are very well-known types of stablecoins. They are digital assets with value pegged to real gold. Being a type of cryptocurrency, Mita et al. (2019) and Sidorenko (2020) contend that stable coins are designed to mitigate the unpredictable market price swings seen in traditional cryptocurrencies. As for Wei (2018), Wang et al. (2020), and Baur and Hoang (2020), stablecoins are viewed as secure financial assets providing refuge during periods of economic and financial turmoil.

In this paper, we conduct an empirical investigation of the connectedness and spillover relationships between Bitcoin, gold, gold-backed cryptocurrencies and energy commodities (crude oil and natural gas) amid the recent COVID-19 pandemic and the ongoing Russia-Ukraine war. The examination of the connectedness among these assets is conducted using the quantile connectedness approach proposed by Ando et al. (2022), Bouri et al. (2021), and Chatziantoniou et al. (2021), based on the connectedness approach of Diebold and Yilmaz (2012; 2014). Our findings reveal diverse influence dynamics among digital assets, with Gold, DGX, and PAXG emerging as key contributors to the network's total connectedness. Notably, the cTCI/TCI ratio underscores substantial direct linkages, emphasizing significant interconnections among digital assets. DGX acts as a principal information transmitter, while gas plays a crucial role as a primary receiver, suggesting its potential as a diversifier. The time-quantile analysis highlights heightened connectedness during significant events, providing valuable insights for investors and risk managers. Results underscore varying roles of assets, with PAXG persistently acting as a net transmitter and Bitcoin and Gold displaying nuanced patterns. The time-frequency analysis at the median quantile emphasizes the dominance of short-term dynamics, prompting the need for adaptive risk management strategies.

To the best of our knowledge, we are among the first to scrutinize the correlations mentioned, considering the current pandemic and war circumstances. Given that economic downturns, acts of terrorism, infectious diseases, conflicts, and similar events frequently play a pivotal role in the analysis of portfolio risk, our findings may attract the attention of investors in both commodity and digital currency markets. In comparison to previous works solely focusing on the connectedness of Bitcoin and gold with energy commodities, our study adds the investigation of the capacity of gold-backed cryptocurrencies. By incorporating these elements, the examination expands the exploration of different qualities to encompass digital currencies. This addresses a gap in the existing literature that might overlook the distinctive features of these digital gold assets. Furthermore, by employing an innovative Quantile-VAR methodology at the median quantile and diverse quantiles, this study provides a nuanced analysis that surpasses conventional methods.

The outcomes of our research have practical significance for policymakers and investors navigating through unpredictable economic conditions. It provides valuable insights for formulating effective risk management strategies and making informed investment decisions across various crises.

The rest of this paper is as follows: Section 2 presents the literature review. Section 3 introduces the data and methodology. Section 4 discusses empirical results. Finally, Section 5 concludes.

2. LITERATURE REVIEW

The repercussions of the recent crises on commodity markets imply that engagements in these markets have become riskier, potentially leading to more significant losses. Consequently, investors in commodities should contemplate modifying their strategies for allocating capital by integrating diversifying, hedging, and safe-haven assets into their portfolios focused on commodities.

In line with studies by Baur and Lucey (2010) and Baur and McDermott (2010), an asset is considered a diversifier if it is positively connected with other assets. An asset is considered a hedge if it is unconnected or negatively connected with other assets during normal times. Whereas, an asset is deemed a safe haven if it is unconnected or negatively connected with other assets during periods of turmoil.

Gold is extensively discussed as a hedging and safe haven asset in literature. Baur and Lucey (2010) as well as Baur and McDermott (2010) investigate gold's ability to hedge and act as a safe haven against American and European stocks. They find that the yellow metal serves as both a hedging and a safe haven tool during severe stock market situations. Similar findings are also noted by Reboredo (2013) and Ciner et al. (2013). Triki and Ben Maatoug (2021) assert that gold is an ideal diversifier and a safe haven during times of tremendous stress. Shahzad et al. (2020) explore the diversifying, hedging, and safe haven capabilities of gold, revealing its unquestionable role as a safe haven and hedge.

Using the NARDL model, Ghorbel et al. (2022) discovered that gold can operate as a suitable hedging tool or safe haven in the long term. Adekoya et al. (2021) found that gold serves as an ideal hedge against risks associated with the crude oil market amid the COVID-19 pandemic. Dutta et al. (2020) found that gold served as a resilient safe haven asset for crude oil markets amidst the COVID-19 pandemic. Shakil et al. (2018) identified gold as an ideal safe haven for commodities, noting that its inclusion in an investment portfolio contributes to risk mitigation during financial crises. Oosterlinck et al. (2022), using the DCC model for the periods before and during the 2022 Russia-Ukraine military conflict, discovered that gold is a perfect diversifier during periods of military tensions. Naeem et al. (2022) examined the potential characteristics of gold as a secure haven asset and a hedging tool for industrial metals and agricultural commodities before and after the Global Financial Crisis (GFC). They found a limited correlation between gold and commodities, supporting the assertion that gold effectively serves as a safe haven during the turbulent times of the GFC.

Wang et al. (2023) asserted that gold functions as a beneficial safe-haven instrument for the crude oil market, both before and during the pandemic. Cui et al. (2023) also stated that gold serves as an ideal safe haven for oil during the COVID-19 pandemic. Ari et al. (2023) conducted an investigation into the influence of fluctuations in gold prices on the energy sectors during the COVID-19 pandemic and the geopolitical tensions between Russia and Ukraine. Their findings indicated that changes in gold returns do not exert an impact on the returns of the energy industry, establishing it as a suitable safe haven asset.

Nevertheless, a limited number of investigations challenge gold's capacity to serve as both a hedge and a safe haven. Employing OLS regression, Jeribi and Snene-Manzli (2020) examine gold's hedging and safe haven capabilities both before and during the COVID-19 pandemic. According to their findings, gold did not function as either a hedge or a safe haven for investors in Tunisia during the outbreak. Cheema et al. (2020) asserted that gold acquired a heightened level of risk amid the COVID-19 outbreak and lost its status as a safe haven during this crisis. Bentes et al. (2022) found a reversal in the returns of gold during the health crisis caused by COVID-19. Diaconaşu et al. (2022) posit that the global commodities and stock markets have come under pressure due to the Russian-Ukrainian military conflict, severely affecting the world's gold and financial markets.

In addition to the yellow metal, crypto assets are also renowned as hedging and safe haven instruments that have captured investors' interest. The hedging and safe haven features of cryptocurrencies, notably Bitcoin, have been extensively investigated. For instance, Bouri et al. (2019) examined the diversifying and hedging performance of Bitcoin and other cryptocurrencies for financial equities. Their findings imply that cryptocurrencies are perfect hedging instruments. Using different multivariate GARCH models, Guesmi et al. (2019) investigated the validity of Bitcoin in financial markets, demonstrating that Bitcoin may be used to hedge the risk of investment in various financial assets. Corbet et al. (2020b) explored the impact of investors' sentiment related to the COVID-19 pandemic expansion on cryptocurrencies' performance, revealing that digital assets not only provide diversification advantages for investors but also serve as safe havens, akin to precious metals, throughout previous crises. Hai Le et al. (2021) also assert that Bitcoin acts as a safe haven during the COVID-19 pandemic.

Tut (2022) contends that Bitcoin, which permits enormous sums of money to be transferred across borders, should improve financial security during times of military conflicts. Bouri et al. (2017a) suggest that Bitcoin effectively operates as a resilient hedge and a secure refuge against variations in commodity markets. Selmi et al. (2018) found that both Bitcoin and gold can serve as assets for diversification, hedging, and safe havens in the face of oil price fluctuations. Naeem et al. (2020) mentioned that cryptocurrencies play a vital role as hedges and safe haven options against commodities. Hoang et al. (2020) suggest that Bitcoin holds the capability to function as a safe haven against fluctuations in commodity markets. Ma (2022) asserted that Bitcoin is an attractive hedging tool against the disruptive effects of the global crude oil market and its escalated prices triggered by the Russia-Ukraine conflict.

On the other hand, Das et al. (2019) determine that Bitcoin does not emerge as a superior asset for hedging compared to gold and the US dollar, despite possessing certain safe haven and hedging characteristics. Bouri et al. (2017b) mentioned that Bitcoin functions as a hedge only for global uncertainty indices. Mokni et al. (2021) found that cryptocurrencies do not serve as effective hedges and secure havens amid the health crisis caused by COVID-19. Likewise, Cheema et al. (2020) and Jeribi and Snene-Manzli (2020) discover that Bitcoin cannot be considered a safe haven for assets amid the substantial market decline of COVID-19.

In the perspective presented by Taleb (2021), Bitcoin is contended to be inadequate as a store of value in both short and long-term contexts. Additionally, it is asserted that Bitcoin does not fulfill the role of a hedge against inflation and proves ineffective as a safe haven during times of crisis. In their investigation amid the COVID-19 crisis, Wen et al. (2022) scrutinize the dynamic spillover effects of Bitcoin prices on oil and stock markets. Their findings illustrate the inadequacy of Bitcoin's safe haven attribute. Yatié (2022) mentions that Bitcoin proved ineffective as a safe haven during the military conflict between Russia and Ukraine. Akbulaev and Abdulhasanov (2023) investigate the correlation between Bitcoin and energy commodities prices (natural gas and crude oil). Their results demonstrate that a rise in the value of Bitcoin leads to an escalation in the prices of oil and gas.

Given the considerable unpredictability and volatility of traditional cryptocurrencies, there has been notable attention directed towards exploring the capabilities of alternative types of crypto assets, such as stablecoins, to address this issue. These digital currencies have their value tied to (relatively) stable assets like gold and the US dollar. Cryptocurrencies backed by gold are widely recognized as a prevalent category within the stablecoins realm.

Baur and Hoang (2020) examine the safe haven property of stablecoins against Bitcoin price volatility, discovering that they function as safe havens. Xie et al. (2021) test the safe haven capacity of stablecoins for conventional cryptocurrencies during the COVID-19 outbreak. Their findings corroborate with their safe-haven features both before and during the outbreak. Ncir et al. (2021) demonstrated that, during the COVID-19 crisis, cryptocurrencies backed by gold showcase reduced risk levels when contrasted with Bitcoin. Yousaf and Yarovaya (2022) claimed that investing funds in gold-backed cryptocurrencies diminishes the risk linked to portfolios in the equity sector during the COVID-19 pandemic. Also, Syuhada et al. (2022) found that incorporating stable coins into a portfolio comprising oil and Bitcoin substantially diminishes the overall portfolio risk amid the COVID-19 period. Hampl et al. (2022) investigate the safe haven ability of traditional cryptocurrencies and stablecoins for financial markets during the Russo-Ukrainian battle. Their results reveal that stablecoins may act as a safe haven for gold and stock markets during this political crisis.

However, heightened instability was observed in gold-backed digital currencies during the COVID-19 crisis, as noted by Wasiuzzaman and Abdul Rahman (2021) and Irfan et al. (2023). Jalan et al. (2021) also discovered that stable coins were volatile during the COVID-19 health crisis. While investigating the price fluctuations of stablecoins and their correlation with the volatility of Bitcoin, Grobys et al. (2021) reveal that the implied volatility of stablecoins is erratic and responds to the real-time volatility of Bitcoin. Kakinuma (2023) also states that stablecoins act as poor safe havens during the COVID-19 crisis.

Derived from the aforementioned inquiries, it becomes apparent that the connectedness among digital and financial assets and their diversification, hedging, and safe haven attributes exhibit fluctuations over time and in different markets. Consequently, a reassessment of these characteristics is imperative considering the COVID-19 pandemic and the military crisis between Russia and Ukraine. Furthermore, we extend our investigation to encompass the capacity of gold, Bitcoin, and gold-backed cryptocurrencies to safeguard against risks associated with commodities, specifically crude oil and natural gas, in times of upheaval.

3. DATA AND METHODOLOGY

3.1. Data

The paper examines the connectedness and spillover relationships between four categories of assets, namely conventional cryptocurrency (Bitcoin), financial assets (gold), gold-backed currencies (PAXG and DGX), and energy assets, namely oil (WTI) and gas (Natural Gas Futures NGK2). The data span from September 27, 2019, to October 31, 2023. The timeframe is marked by major events such as the global COVID-19 pandemic and the war between Ukraine and Russia. These events had a substantial impact on financial markets, allowing us to examine not just the dynamic connectedness within the digital (respectively, financial) market and energy market but also the extent to which these assets are subject to instability caused by broader market shifts. The returns of the different variables are calculated by employing the formula $R_t = \ln (P_t/P_{t-1})$, with P_t denoting the price for the current day.

3.2. Methodology

To analyze the quantile spillover mechanism across various digital and financial markets, we employ the quantile connectedness approach proposed by Ando et al. (2022), Bouri et al. (2021), and Chatziantoniou et al. (2021), based on the connectedness approach of Diebold and Yilmaz (2012; 2014). We begin by computing the overall connectedness measures using a quantile vector autoregression (QVAR(p)). The model can be presented as follows:

$$x_t = \mu_t(\tau)+\Phi_1(\tau)x_{t-1})+\Phi_2(\tau)x_{t-2+\ldots+}\ \Phi_p(\tau)x_{t-p}\mu_t(\tau) \tag{1}$$

Where x_t and x_{t-j} are vectors representing endogenous variables with dimensions $N \times 1$. The parameter τ is a closed interval, which lies within the range [0, 1], while p represents the lag length of the QVAR model. (τ) is a $N \times 1$ dimensional vector that represents the conditional mean, $\Phi_j(\tau)$ is a $N \times N$ dimensional matrix of QVAR coefficients, and $\mu(\tau)$ is a $N \times 1$ dimensional error vector with an $N \times N$ dimensional error variance–covariance matrix, (□).

Then, we apply the forward M-step Generalized Forecast Error Variance Decomposition (GFEVD), since the first equation needs to be transformed into the QVMA (∞) form by applying Wold's theorem. The QVMA(∞) can be obtained from the following equation:

$$x_t = \mu(\tau) + \sum_{j=1}^{p} \Phi_j\ (\tau)x_{t-j} + u_t\ (\tau) = \mu(\tau) + \sum_{i=0}^{\infty} \Psi_i(\tau)u_{t-i} \tag{2}$$

Next, we calculate the generalized forecast error variance decomposition (GFEVD) with a forecast horizon of H (Table 1). This is a central step in the connectedness approach (Koop et al., 1996; Pesaran and Shin, 1998) as follow:

$$\theta_{ij}^{g}(H) = \frac{\left(\Sigma\left(\tau\right)_{jj}^{-1}\sum_{h=0}^{H}((\Psi h(\tau)\Sigma(\tau)\Big)ij\right)2}{\sum_{h=0}^{H}\left(\Psi h(\tau)\Sigma(\tau)\Psi' h(\tau)\right)ii} \tag{3}$$

$$\tilde{\theta}_{ij}(H) = \theta_{ij}(H)\sum_{k=1}^{N}\theta_{ij}\ (H)\ , \quad \text{with} \quad \sum_{i=1}^{N}\tilde{\theta}_{ij}(H) = 1 \ \text{and} \ \sum_{j=1}^{N}\tilde{\theta}_{ij}(H) = N \tag{4}$$

Following Diebold and Yilmaz (2012) approach, the GFEVD based spillover measures are defined as follows:

The total directional connectedness with respect to others assesses how much an impact in series i influences all other series j.

$$TO_i(H) = \sum_{i=1, i\neq j}^{N}\tilde{\theta}_{ji}\ (H) \tag{5}$$

The total directional connectedness originating from others quantifies the level of impact on series i caused by shocks in all other series j.

$$FROM_i(H) = \sum_{i=1, i\neq j}^{N}\tilde{\theta}_{ij}(H) \tag{6}$$

The overall net total directional connectedness captures the difference between the total directional connectedness towards others and the total directional connectedness from others. This disparity can be interpreted as the net impact of series i on the predefined network.

$$NET_i(H) = TO_i(H) - FROM_i(H) \tag{7}$$

The computation of the overall total connectedness index (TCI), which evaluates the degree of interconnectedness within the network. A higher value of TCI signifies increased market risk, while a lower value indicates the opposite (Chatziantoniou et al., 2021).

$$TCI(H) = N - 1\sum_{i=1}^{N} TO_i(H) = N - 1\sum_{i=1}^{N} FROM_i(H) \tag{8}$$

Using Stiassny's (1996) spectral decomposition method, we intend to analyze the link between connectedness and frequency.

Table 1: Connectedness table based on the FEVD approach

Variables	y_1	y_2	y_k	*From*
y_1	$C_{1\leftarrow 1}^{H}$	$C_{1\leftarrow 2}^{H}$	$C_{1\leftarrow K}^{H}$	$F_{1\leftarrow j} = \sum_{j=1}^{K} C_{1\leftarrow j}^{H}, j \neq 1$
y_2	$C_{2\leftarrow 1}^{H}$	$C_{2\leftarrow 2}^{H}$	$C_{2\leftarrow K}^{H}$	$F_{2\leftarrow j} = \sum_{j=1}^{K} C_{2\leftarrow j}^{H}, j \neq 2$
y_k	$C_{K\leftarrow 1}^{H}$	$C_{K\leftarrow 2}^{H}$	$C_{K\leftarrow K}^{H}$	$F_{K\leftarrow j} = \sum_{j=1}^{K} C_{K\leftarrow j}^{H}, j \neq K$
To	$T_{i\leftarrow 1} = \sum_{i=1}^{K} C_{i\leftarrow 1}^{H}$ $i \neq 1$	$T_{i\leftarrow 2} = \sum_{i=1}^{K} C_{i\leftarrow 2}^{H}$ $i \neq 2$	$T_{i\leftarrow K} = \sum_{i=1}^{K} C_{i\leftarrow K}^{H}$ $i \neq K$	$\frac{1}{K}\sum_{i,j=1}^{K} C_{i\leftarrow j}^{H}$ $i \neq j$
Net	$T_{i\leftarrow 1} - F_{1\leftarrow j}$	$T_{i\leftarrow 2} - F_{2\leftarrow j}$	$T_{i\leftarrow K} - F_{K\leftarrow j}$	

Following Diebold and Yilmaz (2009 ; 2014) and Zhang (2017), H is set to be 10 days

Firstly, we inspect the frequency response function, represented as $(e^{-iw}) = \sum_{h=0}^{\infty} e^{-iw} h \Psi h$, where $i = \sqrt{-1}$ and ω is the frequency.

$$S_x(w) = \sum_{h=-\infty}^{\infty} E(x_t x_t - h')e^{-iw}h = \left(e^{-iw}h\right)_t \Psi'(e^{+iw}h) \quad (9)$$

Similarly, the frequency-based Generalized Forecast Error Variance Decomposition (GFEVD) is a fusion of the spectral density and the GFEVD. In fact, normalizing the frequency GFEVD is key, and is presented as follows:

$$\theta_{ij}\ (H) = \frac{(\Sigma(\tau))_{jj}^{-1} \sum_{h=0}^{\infty} ((\Psi(\tau)e^{-iw} h\Sigma(\tau))ij\ )2}{\sum_{h=0}^{H} (\Psi e^{-iw} h)\Sigma(\tau)\Psi(\tau)(e^{iw} h)ii} \quad (10)$$

$$\tilde{\theta}_{ij}(w) = \theta_{ij}(w) \sum_{k=1}^{N} \theta_{ij}\ (w) \quad (11)$$

The term $\theta ij\ (\omega)$ signifies the proportion of the spectrum of the i^{th} series at a given frequency ω that can be attributed to a shock in the j^{th} series. This measure is devoted to as a within-frequency sign, as it aids in assessing the interconnectedness between the two series at that particular frequency. To assess connectedness through both short-term and long-term time frames, instead of focusing on a single frequency, we aggregate all frequencies within a stated range, denoted as: $d = (a, b)$: a, bÎ $(-\pi, \pi)$, $a<b$:

$$\tilde{\theta}_{ij}(d) = \int_{b}^{a} \tilde{\theta}_{ij}(w)\, dw \quad (12)$$

Consequently, we have the ability to compute similar connectedness measures as those introduced by Diebold and Yılmaz (2012; 2014). Nevertheless, in this case, these measures are recognized as frequency connectedness measures. They allow us to assess the transmission of effects within specific frequency ranges (represented by d), which can be interpreted in a comparable manner:

$$TO_i(d) = \sum_{i=1, i\neq j}^{N} \tilde{\theta}_{ji}\ (d) \quad (13)$$

$$FROM_i(d) = \sum_{i=1, i\neq j}^{N} \tilde{\theta}_{ij}(d) \quad (14)$$

$$NET_i\,(d) = TO_i\,(d) - FROM_i\,(d) \quad (15)$$

$$TCI(d) = N - 1\sum_{i=1}^{N} TO_i(d) = N - 1\sum_{i=1}^{N} FROM_i(H) \quad (16)$$

Here, we consider two frequency bands that capture short-term and long-term dynamics. The first band, $d1 = (\pi/5, \pi)$, covers a range of 1-5 days, while the second band, $d2 = (0, \pi/5]$, encompasses timeframes from 6 days to an infinite horizon. Therefore, $(d1)$, $FROMi(d1)$, $NETi(d1)$, and $TCI(d1)$ represent short-term total directional connectedness towards others, short-term total directional connectedness from others, short-term net total directional connectedness, and short-term total connectedness index, respectively. Alternatively, $(d2)$, $FROMi(d2)$, $NETi(d2)$, and $TCI(d2)$ depict long-term total directional connectedness towards others, long-term total directional connectedness from others, long-term net total directional connectedness, and long-term total connectedness index, respectively.

4. EMPIRICAL RESULTS

4.1. Descriptive Statistics

Table 2 presents the descriptive statistics for the daily return series. All the returns exhibit stationarity at the 1% significance level, as indicated by the ERS unit root test. Most variables display negative skewness and high kurtosis, indicating the presence of extreme negative observations. In contrast, DGX and PAXG show positive skewness and excess kurtosis for DGX, suggesting an asymmetric and fat-tailed nature of the asset. The analysis is in line with the Jarque-Bera test, confirming the non-normality of the returns. Furthermore, based on Kendall's coefficients, the analysis reveals significant dependencies among various assets. The highest dependence is observed between Gold and PAXG.

4.2. Total Dynamic Connectedness

The connectedness indices within the cryptocurrency and energy markets in Table 3 and Table 4 display considerable variation, revealing diverse influence dynamics among different digital assets, with an average value of 18.16%. The "To" connectedness values span a range of 23.52% (Gas) to 61.02% (Gold) percentage points. On the other hand, the "From" connectedness values range from 21.80% (DGX) to 54.01% (PAXG). Notably, DGX and Gold are the most connected markets, demonstrating the highest pairwise connectedness through the network, while Gas and DGX are less connected. The NET values provide a net measure of an asset's connectedness, considering both its influence on others and their influence on it. Precisely, Gold, DGX, and PAXG are shock contributors to the network's total connectedness, while Oil, Gas, and Bitcoin are the main net receivers of shocks from other cryptocurrencies.

Finally, the cTCI/TCI ratio helps assess the importance of direct connections between variables in relation to the overall connectedness of the network. Thus, it compares conditional connectedness (cTCI) to total connectedness (TCI), providing important insights into the network's inner workings (Bas et al., 2023). The results show that the ratio surpasses one, proving the existence of substantial direct linkages between variables that extend beyond the network's general interconnectedness. Our conclusions emphasize the existence of significant interconnections among digital assets. Since the period is long and the results of net connectedness could be general, we use the network plot to analyze the different statuses of the assets studied during three different periods. These would help us identify the quantum and direction of shocks. Using the node color darkness and area, we attempt to convey full-scale information about the system-wise connectedness dynamics. The results in Figures 1-3 show that before COVID, PAXG, Bitcoin, and WTI are the net transmitters of shocks to the network, with PAXG as the main transmitter, while DGX, gas, and Gold are net receivers, with a clear disconnection with Gold. During the pandemic, dramatic

Table 2: Descriptive statistics

Variables	Bitcoin	Gold	WTI	Gas	DGX	PAXG
Mean	0.001	0.000	0.000	0.000	0.000	0.000
	(0.297)	(0.379)	(0.781)	(0.785)	(0.982)	(0.500)
Variance	0.002***	0.000***	0.002***	0.002***	0.012***	0.000***
Skewness	−1.686***	−0.427***	−3.159***	−0.118	2.400***	0.015
	(0.000)	(0.000)	(0.000)	(0.116)	(0.000)	(0.838)
Ex.Kurtosis	20.345***	3.431***	61.500***	1.410***	120.835***	5.552***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
JB	18783.310***	552.046***	168810.680***	90.287***	645901.922***	1361.700***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ERS	−11.930***	−7.782***	−11.594***	−13.093***	−16.859***	−7.873***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
kendall	Bitcoin	Gold	WTI	Gas	DGX	PAXG
Bitcoin	1.000***	0.081***	0.050**	0.014	0.223***	0.103***
Gold	0.081***	1.000***	0.094***	0.003	0.065***	0.582***
WTI	0.050**	0.094***	1.000***	0.074***	0.030	0.098***
Gas	0.014	0.003	0.074***	1.000***	−0.004	−0.005
DGX	0.223***	0.065***	0.030	−0.004	1.000***	0.085***
PAXG	0.103***	0.582***	0.098***	−0.005	0.085***	1.000***

Figure 1: Net-pairwise directional connectedness before COVID

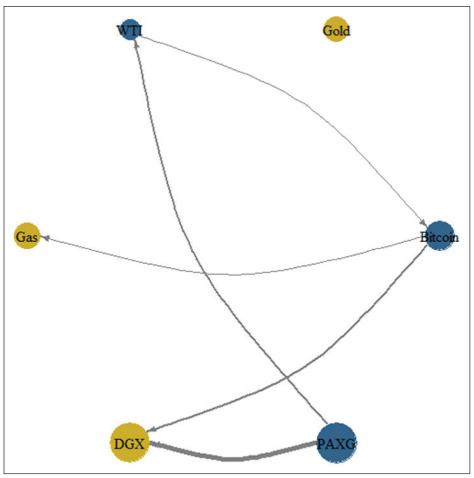
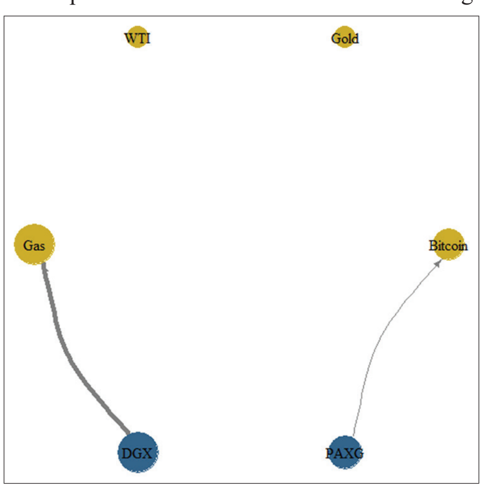
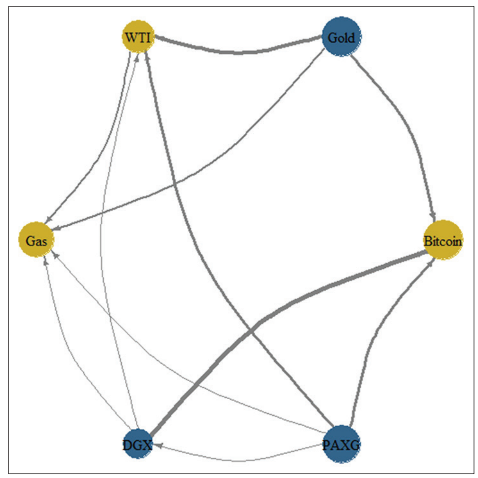


Figure 2: Net-pairwise directional connectedness during COVID



changes are recorded. In fact, both Gold and oil are disconnected from the system, with no arrows linking them to the other assets. During the war, connections are rebuilt, and Bitcoin, oil, and gas turn out to be net receivers of shocks, while DGX, PAXG, and

Figure 3: Net-pairwise directional connectedness during war



Gold are net transmitters of volatility to the system.

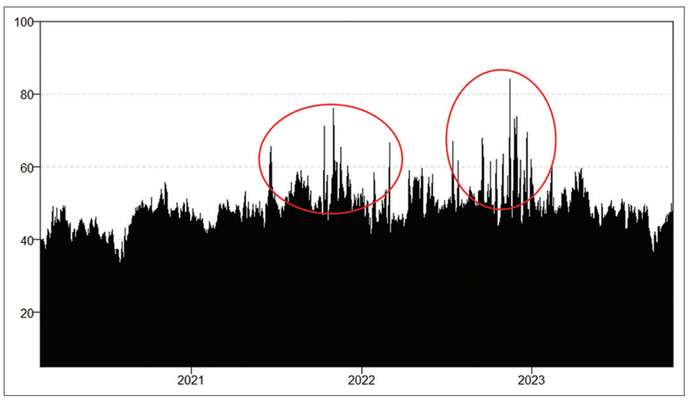
In Figure 4, we analyze the evolution of the TCI over the sample period. During the period around 2022 and the end of 2023, the analysis reveals distinct peaks in the cryptocurrency and energy markets, surpassing 60%. The first substantial peak occurred in the last months of 2021 and the early months of 2022, coinciding with the COVID-19 pandemic and the onset of the Russia-Ukraine war. This period was marked by a substantial increase in the overall spillover between cryptocurrencies and different energy commodities (Amar et al., 2023), considering the importance of Russia and Ukraine as producers of energy and the growth of the cryptocurrency market at the end of 2021 (Mensi et al., 2023). Following this, a significant increase was observed around 2023, marked by high degrees of connectedness between the assets, reaching about 80%. This may be explained by the occurrence of the American banking crisis, namely the Silicon Valley Bank collapse that tremendously impacted the prices of cryptocurrencies, especially Bitcoin and stablecoins (Yousaf et al., 2023; Galati and Capalbo, 2023).

An in-depth analysis of the graph reveals an increasing trend in overall connectivity starting from the onset of 2021, with a notable inclination towards reverting to previous values by the third quarter of 2023. These high points underline the significant influence of crypto-asset risks, gold and energy assets on network interconnectedness, underlining the relationship between market fluctuation and the overall connectedness of the studied ecosystem (Ghorbel et al., 2022; Wan et al., 2023).

4.3. Net Total and Pairwise Directional Connectedness

Figure 5 illustrates the net total directional connectedness for each cryptocurrency, Gold, and energy product. We note that a positive value related to each asset signifies its role as a shock transmitter within the network, while a negative value signifies its position as a receiver within the network. It means that it influences (is influenced by) all the system's remaining variables more than the others. Numerous peaks are depicted at different points in time, representing significant changes in network dynamics. Specifically, the DGX market emerges as the principal source of network information transmission, while the gas market emerges as the primary network information receiver, suggesting its possible use as a diversifier. Moreover, Gold, PAXG, oil, and Bitcoin demonstrate varying patterns in net spillovers over the study period. Bitcoin displays phases of being a net shock transmitter at various points in time during the beginning of 2020 (COVID). Also, Gold is found to be an almost net transmitter, except during the war between Russia and Ukraine (first half of 2022). These findings suggest that both Bitcoin and Gold lost their safe-haven characteristics during the COVID-19 pandemic, corroborating the results of Cheema et al. (2020) and Jeribi and Snene-Manzli (2020). Besides, the findings indicate that the yellow metal outperformed Bitcoin as a safe haven only during the Russia-Ukraine war, supporting the conclusions drawn by Ari et al. (2023) and Fakhfekh et al. (2023).

Figure 4: Total Dynamic Connectedness between 2020 and 2023



4.4. Total and Net Connectedness using Quantile Analysis

A deeper understanding of market dynamics could be provided by the analysis of the total (Figure 6) and net directional connectedness (Figures 7-12) of cryptocurrencies, gold, oil and gas in time-quantile space. Indeed, the heat-map showed in Figure 6 was generated using a 100-day rolling window and a 20-day ahead forecast based on the QVAR(1) model. The timeline is shown by the x-axis, and the quantiles, which range from 0.05 to 0.95 and are iterated at 1% intervals, are represented by the y-axis. Warmer shades on the plot indicate greater levels of connectedness. The results prove that connectedness is very high both for highly negative returns (below the 20% quantile) and for highly positive changes (above the 80% quantile). We can conclude that the total connectedness is symmetric. In addition, the mean quantile represents the total average connectedness during the whole period. We find evidence of the existence of distinct values at precise intervals. Several short periods of high connectedness are recorded during the end of 2020 and the first half of 2021, during the beginning of 2022, and the beginning of 2023, coinciding with the COVID-19 pandemic, the Russia-

Figure 5: Net total directional connectedness. Between 2020 and 2023

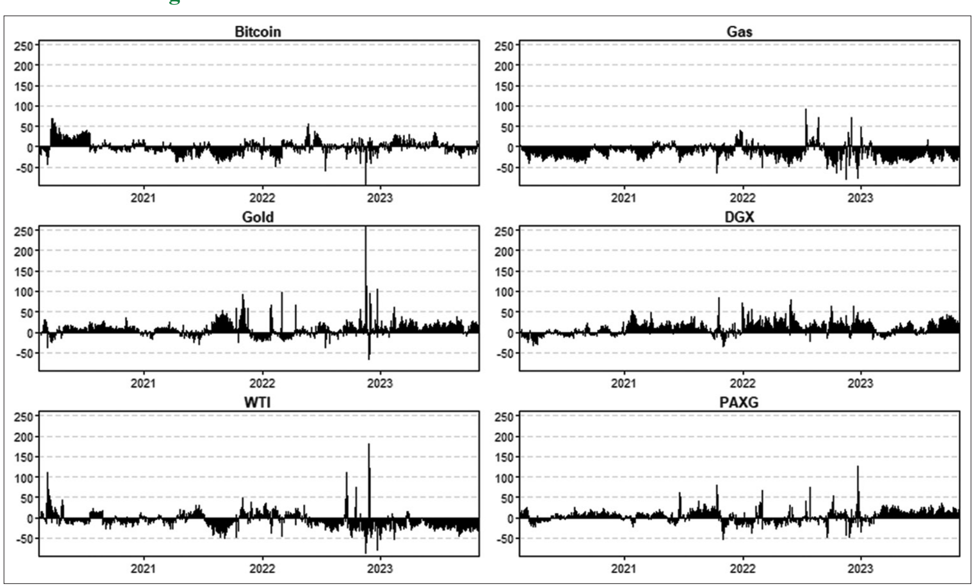


Figure 6: Dynamic total connectedness for all markets across quantiles

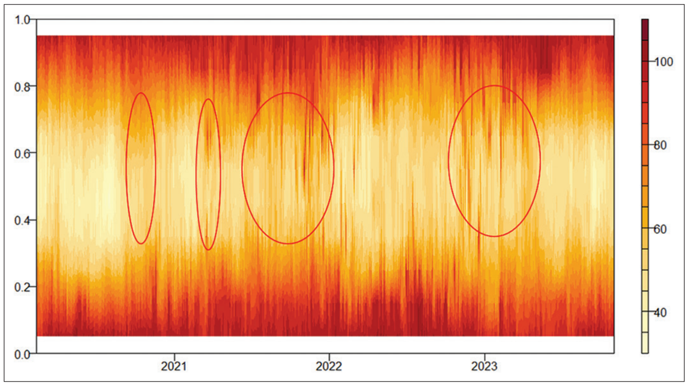


Figure 7: Dynamic total net connectedness for gas across quantiles

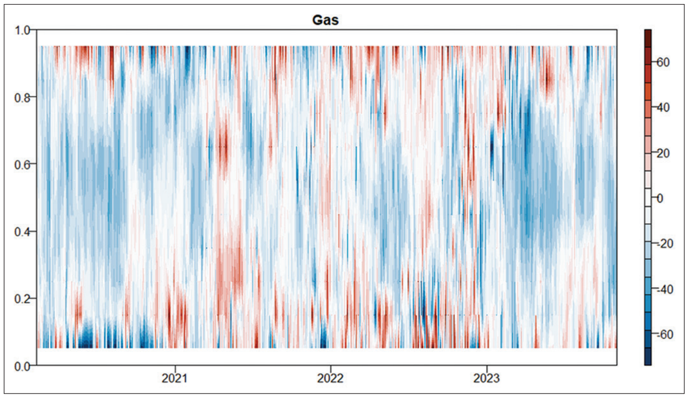


Figure 8: Dynamic total net connectedness for oil across quantiles

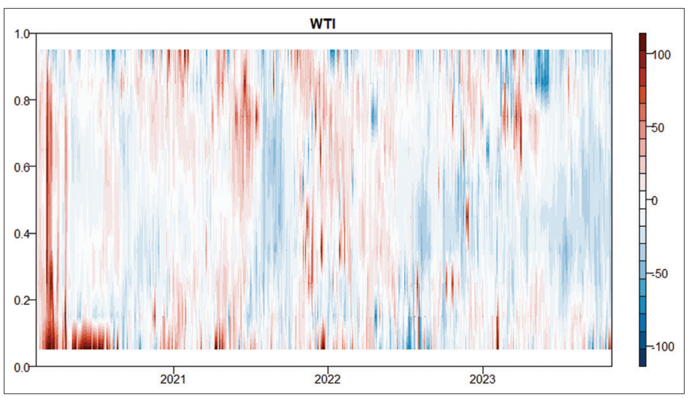


Figure 9: Dynamic total net connectedness for PAXG across quantiles

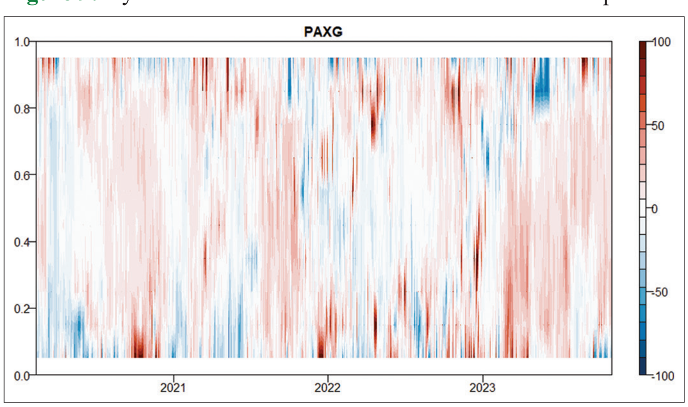


Figure 10: Dynamic total net connectedness for DGX across quantiles

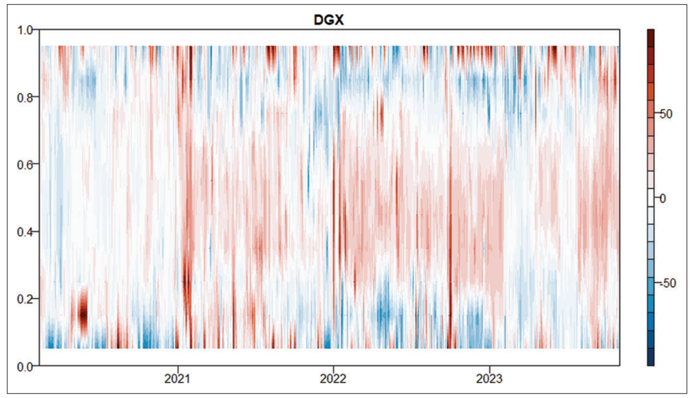


Figure 11: Dynamic total net connectedness for gold across quantiles

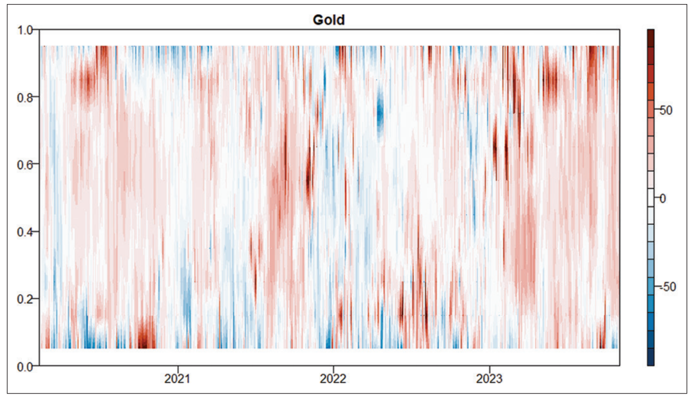
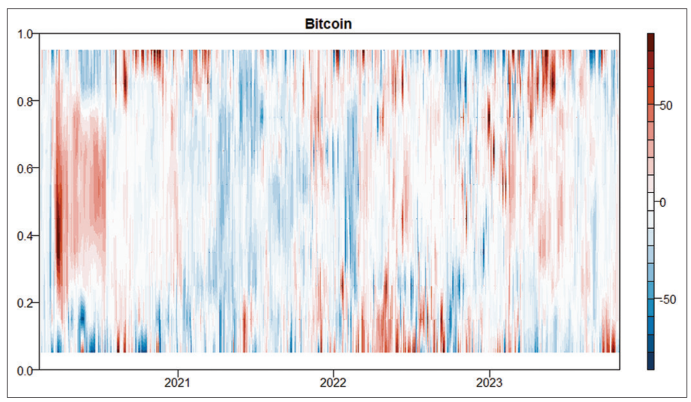


Figure 12: Dynamic total net connectedness for bitcoin across quantiles



Ukraine war, and the Silicon Valley Bank collapse. As stated by Blanka and Karolina (2020), this discovery indicates that the extent of interdependence is heavily dependent on notable events or incidents.

As previously mentioned, Figures 7-12 present the quantile net directional spillovers. Warmer red shades on these plots indicate a net-transmitting asset and blue shades designate a net-receiving asset. We will focus on the two crisis periods, the global pandemic, and the war between Russia and Ukraine. The aim is to understand how investors respond to various market conditions, encompassing bearish (low quantile), stable (middle quantile), and bullish (high quantile) scenarios. Our research reveals that evolving attributes over time play a crucial role in identifying numerous economic events that shape the dynamic transmission of impacts across various quantiles. Our results reveal that gas predominantly assumes a role as a recipient during COVID and wartime. However, in the interim between these crises, it exhibits a dual role, intermittently functioning as both a recipient and a transmitter of systemic shocks.

The empirical evidence reveals that during the initial half of 2020, oil predominantly functions as a pronounced transmitter, particularly within lower quantiles. As the timeline progresses towards 2021 and 2022, its transmission propensity notably wanes. Conversely, beyond these specified intervals, oil assumes a recipient role, exhibiting pronounced prominence, notably at the 0.5 quantile in the latter part of 2022, and consistently across all quantiles throughout 2023.

Also, the findings consistently indicate PAXG's persistent role as a pronounced net transmitter throughout the study's duration across nearly all quantiles. Noteworthy exceptions include brief intervals within specific quantiles, notably the lower quantiles observed during the initial half of 2020 and 2021. Its enduring status as a net transmitter extends notably into 2023, displaying an intensified influence compared to subsequent periods, underscoring its prolonged and heightened transmission characteristics.

DGX prominently embodies its role as a shock transmitter within the 0.5 quantile, persisting from early 2021 through 2022 and extending into late 2023, while displaying a receptive stance in alternative periods. The heatmap delineates a conspicuous asymmetry in its positioning between extreme quantiles. Notably, DGX consistently operates as a shock transmitter in the bearish quantiles and adopts a receiver role in the bullish quantile, signifying a marked dichotomy in its influence amidst diverse market sentiments.

Gold assumes a predominant role as a persistent net transmitter throughout the majority of the observed period, barring specific intervals around 2022, notably prominent within extreme quantiles. Noteworthy is the discernible asymmetry in transmission observed from the inception of the study until the initial half of 2022, following which the status of net transmission becomes prevalent across all quantiles.

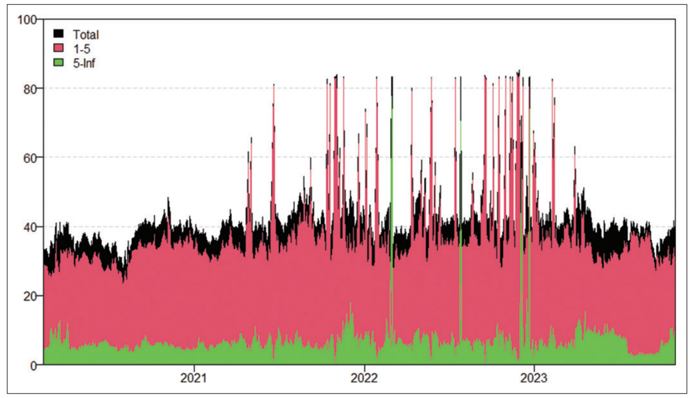
Finally, Bitcoin exhibits a distinct pattern, operating as a pronounced net transmitter in the 0.5 quantile during the initial half of 2020. Transitioning into 2021, it assumes a consistent role as a net receiver, notably observed within the middle quantile. Subsequently, a nuanced and fluctuating trend emerges, portraying Bitcoin's status as heterogeneous or shifting between functioning as a transmitter and a receiver of shocks.

4.5. Total and Net Connectedness using Time Frequency Analysis in Median Quantile (0.5)

Next, we continue with interpreting the median short-term, long-term, total, and net dynamic connectedness. Such an approach is more significant and supple compared to the initial connectedness approach proposed by Diebold and Yilmaz (2012; 2014). Results are illustrated in Figure 13. According to the results, the frequency-connectedness analysis reveals a prominent fame of short-term dynamics over long-term trends in the financial, gold, and energy markets. This observation underlines the market's sharp sensitivity to instant events and temporary factors. The fact that short-term interconnection prevails suggests that the behavior of the variables studied is affected by rapid adjustments to new information and lively responses to short-term market drivers. This outcome has implications for risk management strategies, stressing the importance of adapting to the rapid and sharp fluctuations associated with short-term dynamics. Investors and others would find value in strategies that take advantage of short-term trends or respond quickly to market changes, aligning their approaches with the observed prevalence of short-term interconnection.

In this context, Chatziantoniou et al. (2021) postulate that the quantile regressions are not sensitive to outliers. Consequently, the QVAR connectedness approach leads to more precise and consistent results. In fact, we find that the standard VAR overestimated the impact of specific and brief short-lived spans (occurring during mid-2021, last 2021 to the end of 2022). To sum it up, we note substantial high market spillovers reaching an average of 40%, with even higher values during stress periods attaining 80%.

Figure 13: Dynamic total connectedness

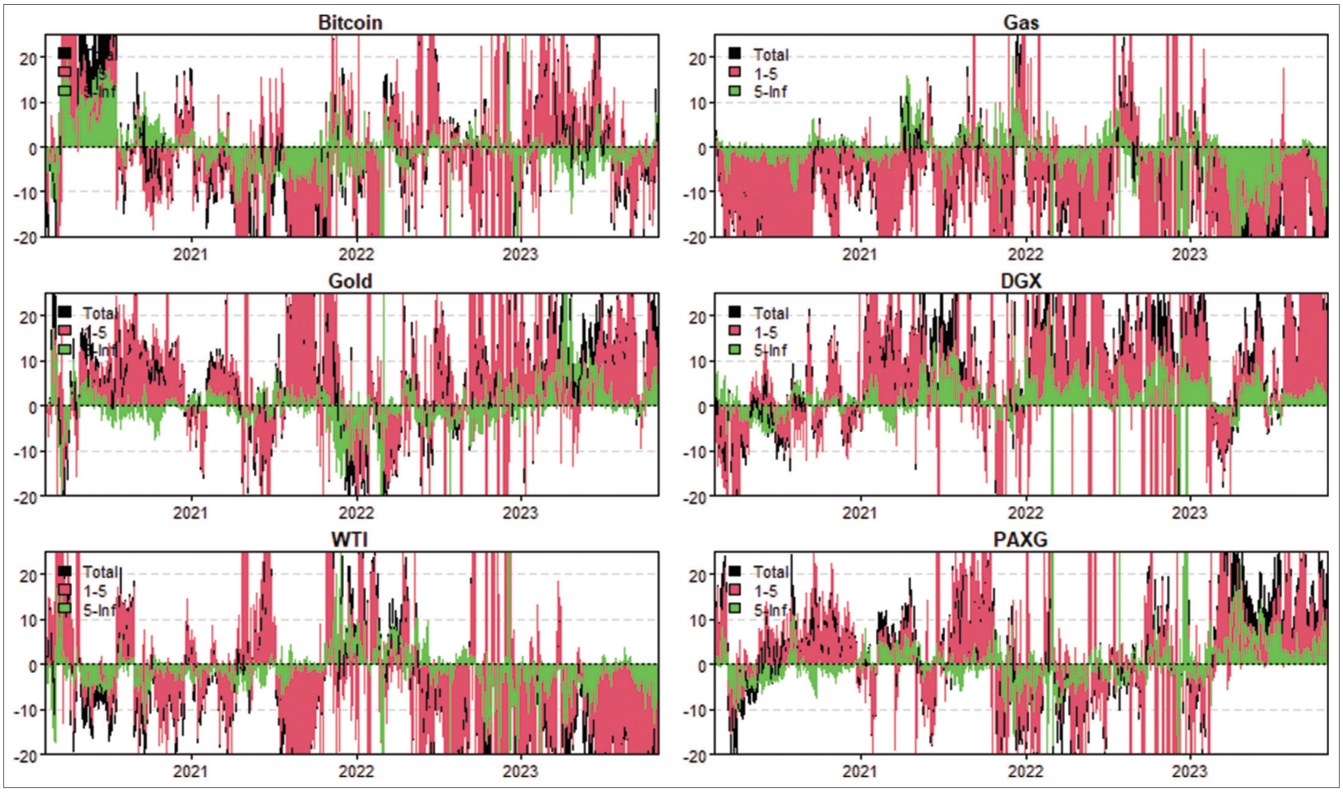


Results are based on a QVAR model with a 100 days rolling-window size, a lag length of order one (BIC), and a 20-step-ahead generalized forecast error variance decomposition. The black area represents the time dynamic connectedness values while the green and blue areas demonstrate the long and short-term results. The corresponding lines illustrate the results of the standard VAR time and frequency domain connectedness approach

Table 3: Average dynamic connectedness

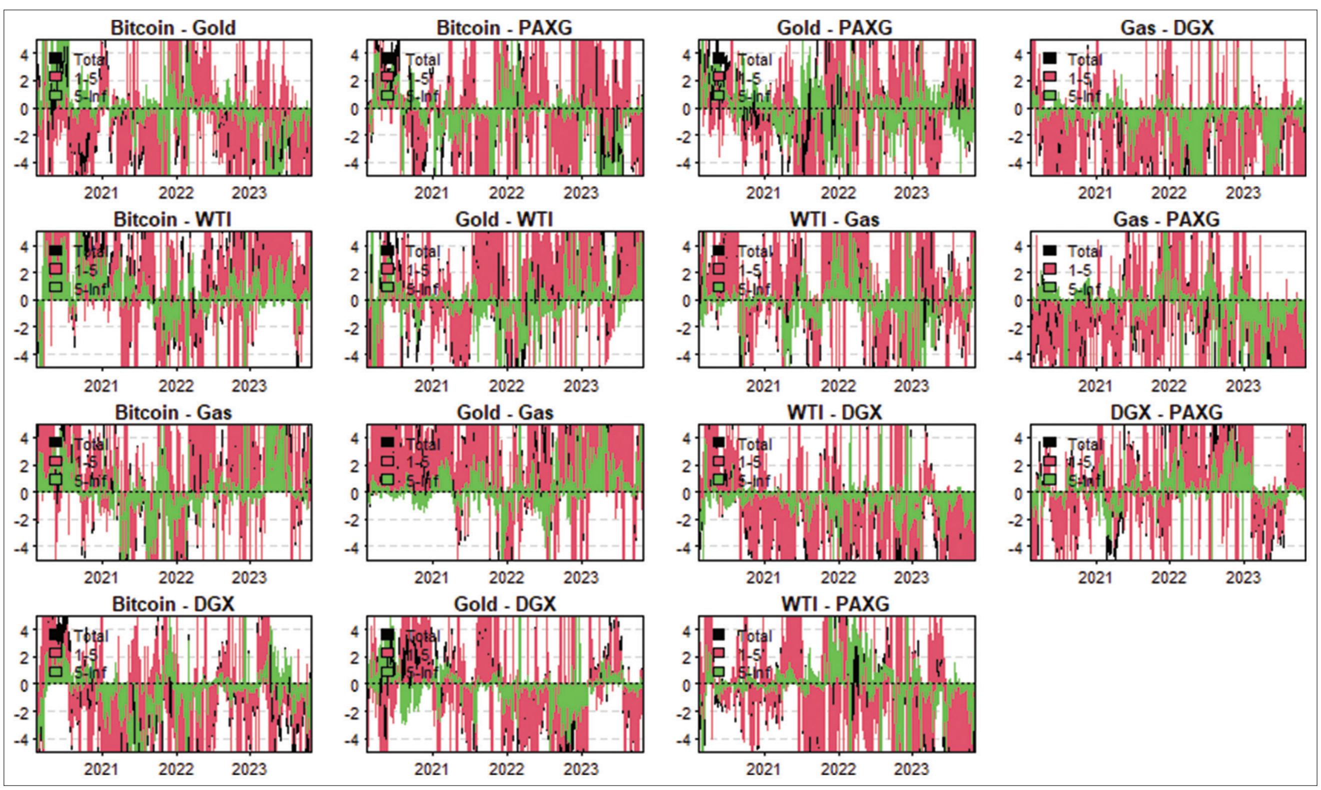
Variables	Bitcoin	Gold	WTI	Gas	DGX	PAXG	FROM
Bitcoin	63.65	9.11	5.33	5.62	7.79	8.49	36.35
Gold	6.97	46.87	6.59	4.33	5.93	29.32	53.13
WTI	7.96	8.56	62.70	6.43	6.35	7.99	37.30
Gas	7.76	8.79	7.49	61.80	6.47	7.68	38.20
DGX	5.77	5.17	3.47	2.64	78.20	4.76	21.80
PAXG	7.60	29.39	6.85	4.52	5.67	45.99	54.01
TO	36.05	61.02	29.73	23.52	32.22	58.24	240.78
NET	−0.30	7.89	−7.57	−14.67	10.42	4.23	48.16/ 40.13

Figure 14: Dynamic total net connectedness



Results are based on a QVAR model with a 100 days rolling-window size, a lag length of order one (BIC), and a 20-step-ahead generalized forecast error variance decomposition. The black area represents the time dynamic connectedness values while the green and blue areas demonstrate the long and short-term results. The corresponding lines illustrate the results of the standard VAR time and frequency domain connectedness approach

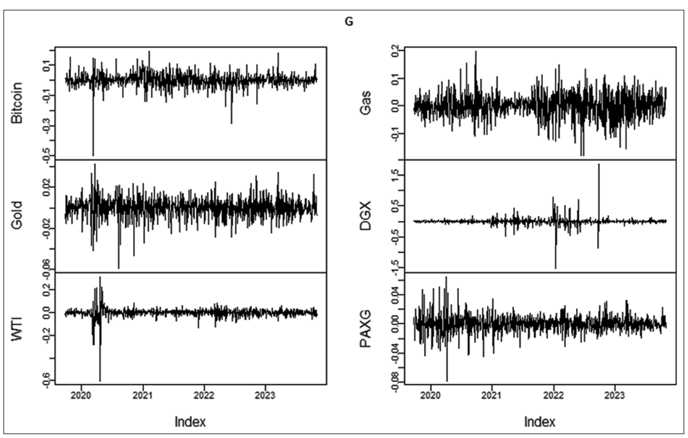
Figure 15: Dynamic net pairwise connectedness



Results are based on a QVAR model with a 100 days rolling-window size, a lag length of order one (BIC), and a 20-step-ahead generalized forecast error variance decomposition. The black area represents the time dynamic connectedness values while the green and blue areas demonstrate the long and short-term results. The corresponding lines illustrate the results of the standard VAR time and frequency domain connectedness approach

Table 4: Average dynamic connectedness of total, short and long term frequency

Variables	Bitcoin.Total	Gold.Total	WTI.Total	Gas.Total	DGX.Total	PAXG.Total	FROM.Total
Total frequency							
Bitcoin	61.49	9.95	5.82	5.81	7.99	8.95	38.51
Gold	7.32	46.09	7.11	4.67	6.16	28.65	53.91
WTI	8.24	9.14	60.97	6.73	6.53	8.39	39.03
Gas	7.99	9.61	7.93	59.59	6.71	8.17	40.41
DGX	6.09	6.24	4.21	3.00	75.00	5.47	25.00
PAXG	7.88	29.04	7.19	4.93	5.92	45.04	54.96
TO	37.52	63.99	32.25	25.14	33.30	59.62	251.83
Inc.Own	99.01	110.07	93.22	84.73	108.30	104.66	cTCI/TCI
Net	−0.99	10.07	−6.78	−15.27	8.30	4.66	50.37/41.97
NPDC	2.00	5.00	1.00	0.00	4.00	3.00	
Short term frequency							
Bitcoin	50.59	8.61	4.99	4.87	6.61	7.38	32.47
Gold	6.08	38.83	5.91	3.97	5.32	23.59	44.86
WTI	6.87	7.95	51.80	5.56	5.65	7.19	33.22
Gas	6.74	8.43	6.96	50.13	5.77	6.97	34.86
DGX	5.13	5.44	3.88	2.67	65.96	4.72	21.84
PAXG	6.94	24.02	6.14	4.22	5.16	38.61	46.48
TO	31.76	54.46	27.88	21.29	28.50	49.85	213.74
Inc.Own	82.35	93.29	79.67	71.41	94.46	88.46	cTCI/TCI
Net	−0.71	9.60	−5.34	−13.58	6.66	3.37	42.75/35.62
NPDC	2.00	5.00	1.00	0.00	4.00	3.00	
Long term frequency							
Bitcoin	10.90	1.33	0.82	0.94	1.37	1.57	6.04
Gold	1.24	7.26	1.21	0.70	0.84	5.06	9.05
WTI	1.37	1.19	9.17	1.17	0.88	1.20	5.82
Gas	1.25	1.18	0.97	9.47	0.94	1.20	5.54
DGX	0.96	0.80	0.33	0.33	9.04	0.75	3.16
PAXG	0.94	5.02	1.05	0.72	0.76	6.43	8.49
TO	5.76	9.52	4.38	3.85	4.80	9.78	38.09
Inc.Own	16.66	16.78	13.55	13.32	13.84	16.20	cTCI/TCI
Net	−0.28	0.47	−1.44	−1.69	1.64	1.29	7.62/6.35
NPDC	2.00	2.00	1.00	1.00	5.00	4.00	



Important insights into the net transmission power of each series can be gained from the interconnection results in Figures 14 and 15, which provide essential insights for investors and risk managers. In particular, the decomposition of total net directional interconnection into short- and long-term dynamics, at a fixed quantile (Q=0.5 in our study), offers valuable insights into the factors influencing the role of each series as a net transmitter or receiver of shocks. We find in our analysis that short-term and long-term dynamics play distinct roles in determining the heterogeneous nature of how a series acts as a net receiver or transmitter, with a predominance of short-term dynamics over long-term dynamics. What stands out is the pre-eminence of short-term dynamics in explaining the dynamic status of reception or net transmission. The studied series' directional interconnection is influenced by instantaneous market conditions and transient factors, highlighting their importance. This nuanced understanding offers investors and risk managers a valuable analytical framework to anticipate and navigate the intricacies of market dynamics over different periods.

5. CONCLUSION

Recently, commodity markets have faced significant challenges arising from diverse crises, such as the COVID-19 pandemic and the military conflict between Russia and Ukraine. The heightened uncertainty and disturbances resulting from these occurrences have contributed to elevated volatility in different commodity sectors, reflecting the increased interdependence of global markets. Energy markets, especially crude oil, have experienced notable fluctuations due to geopolitical tensions and disturbances in the supply chain, affecting both the production and distribution aspects. Fluctuations in demand trends and geopolitical considerations have also impacted the prices of natural gas. In this scenario, commodity investors are advised to modify their approaches to capital allocation by integrating safe-haven assets into their commodity portfolios. This adjustment can aid in alleviating the heightened risks they encounter.

In this paper, we examine the connectedness and spillover relationships between Bitcoin, gold, gold-backed cryptocurrencies and energy commodities (crude oil and natural gas). To do so, we applied the quantile connectedness approach proposed by Ando et al. (2022), Bouri et al. (2021), and Chatziantoniou et al. (2021), based on the connectedness approach of Diebold and Yilmaz (2012; 2014).

The results of total dynamic connectedness within gold, cryptocurrencies, and energy markets yield significant insights. The connectedness indices reveal diverse influence dynamics among different digital assets, with Gold, DGX, and PAXG emerging as key contributors to the network's total connectedness. Notably, the cTCI/TCI ratio emphasizes substantial direct linkages between variables, underscoring significant interconnections among digital assets. The examination of net total and pairwise directional connectedness further highlights the role of assets such as DGX as principal information transmitters and gas as a primary receiver, suggesting its potential as a diversifier. The time-quantile analysis, represented in Figures 6-12, showcases periods of heightened connectedness during significant events like the COVID-19 pandemic, the Russia-Ukraine war, and the Silicon Valley Bank collapse. The results also unveil the varying roles of assets, with PAXG persistently acting as a net transmitter and Bitcoin and Gold displaying nuanced patterns. Interestingly, Gold exhibited certain safe haven characteristics only during the Russia-Ukraine war, surpassing Bitcoin's performance during this geopolitical crisis. Moreover, the time-frequency analysis at the median quantile emphasizes the dominance of short-term dynamics in influencing market behavior, prompting the need for adaptive risk management strategies. Overall, the comprehensive examination provides valuable insights for investors and risk managers, facilitating a nuanced understanding of market dynamics over different periods.

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