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Dynamic spillover effects and interconnectedness of DeFi assets, commodities, and Islamic stock markets during crises

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ABSTRACT

Decentralized Finance (DeFi) assets, commodities, and Islamic stock market cointegration are affected by technological innovations, market dynamics, investor behavior, and crises. This study investigates the dynamics of returns and volatility for three DeFi assets, six commodities, and three Islamic stock markets from December 2019, to March, 2023, and identifies higher spillover effects during crises. Links among the Cross-DeFi, commodity, and Islamic markets significantly influence returns and volatility during crises. Notably, the commodities index emerged as a pivotal and substantial transmitter of risk during the Russian-Ukraine war crisis, with Emerging Markets (EM) being a key recipient. However, during the COVID-19 pandemic, livestock indices assume the role of prominent risk-return spillover receivers. The findings indicate robust returns and volatility interconnected between DeFi assets and Islamic markets with a moderate level of connectivity among commodity groups. WDI, ACWI, and EM explained 75 % of the variance observed during crisis episodes. This study formulates strategic portfolio management within and between connectedness among return volatilities by highlighting the stability of DeFi assets, the diversification potential in commodities, and a balanced option in Islamic markets. Our study provides a deep and insightful understanding of the stakeholders across markets during crises.

1. Introduction

Innovations, growing technology, ethics, market demand-supply dynamics, and global crises have reshaped global financial and ecosystem dynamics. Yousaf and Yarovaya (2022) claimed that DeFi assets are financial services that operate decentralized and peer-to-peer using blockchain technology within the ecosystem. "Decentralized finance" (abbreviated "DeFi") refers to the ecosystem of financial applications being built on top of blockchain and distributed ledger platforms. According to Ali, Ijaz, and Yousaf (2023), decentralized finance (DeFi) has become a viable alternative financial system that can transform the future of digital financial markets. Katsiampa, Yarovaya, and Zięba (2022) state that decentralized finance (DeFi) is currently emerging as a new turning point in the technological development of global finance.

Certain investors perceive DeFi as a hedge against uncertainty or as an asset endowed with the capacity to safeguard and preserve wealth amid market tumult (Kumar, Iqbal, Mitra, Kristoufek, & Bouri, 2022). The COVID-19 pandemic and low interest rate environment have negatively impacted the traditional services offered by financial institutions, reflecting a paradigm shift (Gubareva, 2021). Due to the variety of uses for Defi and their advantages over the established financial system, they have experienced rapid growth (Piñeiro-Chousa, López-Cabarcos, Sevic, & González-López, 2022). DeFi assets engage customers in economic activities such as borrowing, lending, spot trading, online wallets, and derivatives, among others, without the intervention of a third party (such as a bank) (Yousaf, Jareño, & Tolentino, 2023).

Furthermore, commodity markets, including energy, livestock, metals, and agriculture markets, offer diversification benefits. Energy commodities and global stock market prices exhibit higher risk co-movements during the COVID-19 (Younis, Yousaf, Shah, & Longsheng, 2023). Understanding cross-commodity volatility aids asset pricing, portfolio management, and risk assessment. Recognizing daily volatility interconnectivity is vital for policymakers managing contagion and

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destabilization risks and understanding market integration factors (Bouri, Lucey, Saeed, & Vo, 2021). Volatility within oil and metal markets exhibits an inverse leverage effect. Notably, 30 % of the return spillovers within the precious metal domain are attributed to the relationship between platinum, silver, and gold (Batten, Ciner, & Lucey, 2015). Gold and silver exhibit a pronounced interconnection, contrasting with their less prominent linkages to platinum and palladium as co-integration is discerned among diverse commodities and equities (Lau, Vigne, Wang, & Yarovaya, 2017).

Similarly, global capital markets have emerged, along with Islamic equity markets that adhere to Sharia and Islamic law. Islamic stocks are perceived as ethically sound and socially responsible investments (Naeem, Peng, Bouri, Shahzad, & Karim, 2022). Additionally, some scholars posit that Islamic stocks demonstrate enhanced resilience during crises, functioning as safe-haven assets (Akhtar & Jahromi, 2017; Hasan, Rashid, Shafiullah, & Sarker, 2022). Consequently, the market capitalization of Islamic financing increases by approximately 10.3 % annually (Sherif, 2020). However, this study explores the return and volatility network connectedness among DeFi assets, commodities, and Islamic stock markets during the Russia-Ukraine war (RU-war) and COVID-19.

Islamic stock and commodity indices have become popular as more effective hedging tactics against uncertain events such as COVID-19 have opened up investment opportunities. Nagayev, Disli, Inghelbrecht, and Ng (2016) showed that the correlation between commodities markets and the Dow Jones Islamic market index is time-changing. Additionally, Mensi, Hammoudeh, Al-Jarrah, Sensoy, and Kang (2017) discovered that the Islamic finance, technology, energy, and telecommunication sectors and the oil and gold markets are net recipients of risk spillovers. Chang et al. (2020) examined how oil prices affect the Dow Jones Islamic Index and various sectoral stock indices. Specifically, when the oil market is bullish, the price of oil has a negative impact on the Dow Jones Islamic index. Lin and Su (2020) discovered a negative correlation between OVX fluctuations and Islamic stock market returns.

Concerning the COVID-19 pandemic has questioned the financial market interconnectedness through spillovers and altered the relationships between global financial markets by reducing diversification and enhancing shocks and volatility (Bahloul & Khemakhem, 2021). Both conventional and Islamic stock markets are equally affected by COVID-19. Islamic stock markets do not benefit from diversification. According to Hasan et al. (2022), an ideal portfolio structure combines Islamic bonds and conventional bonds. Similarly, several studies explore cross-market dynamics connectedness and risk spillovers during the RU-war (Karkowska & Urjasz, 2023; Wu, Zhan, Zhou, & Wang, 2023; Younis, Gupta, Du, Shah, & Hanif, 2024).

This study offered a significant contribution in the first place since earlier research on the relationships between DeFi assets, commodities, and Islamic stocks (separately from others) mostly concentrated on volatility spillovers among the underlying markets (Lorente, Mohammed, Cifuentes-Faura, & Shahzad, 2023; Piñeiro-Chousa et al., 2022; Shao, Zhong, Liu, & Li, 2021; Yousaf et al., 2023; Zeng, Lu, & Ahmed, 2023). Furthermore, Naeem et al. (2022) studied prominent exchange-traded funds (ETFs) and explored that COVID-19 exhibits negative and stronger co-movements. Precious metals and commodities may experience a dramatic demand shift due to decreased volatility (Cunado, Gabauer, & Gupta, 2021). However, this study concentrates on return-volatility connectedness and spillovers across DeFi assets, commodities, and Islamic stock markets during COVID-19 and the RU-war. The "spillover effect" refers to the unintended consequences or impacts of events in one country on the economies of other countries. The term "interconnectedness" describes how several variables depend on and are influenced by one another.

Investors flock to DeFi assets for quick returns due to crypto-market volatility, whereas Islamic stocks' adherence to ethical principles makes them a safe haven. Second, previous studies specify DeFi asset volatility links across different stock markets (Corbet, Goodell, & Günay, 2022; Ugolini, Reboredo, & Mensi, 2023; Yousaf et al., 2023). However, during the recent crisis, this study offers safe haven insights within and between return and volatility connectedness and spillovers, and the correlation among DeFi assets, commodities, and Islamic stocks. According to contemporary portfolio theory research, if two markets have weak correlations, their portfolios may provide superior benefits for diversification (Fabozzi, Gupta, & Markowitz, 2002).

Inspired by Diebold and Yilmaz (2012) approach, this study uses TVP-VAR to investigate the dynamic connectivity among DeFi assets, commodities, and Islamic stock indices. The TVP-VAR model was selected because it accurately forecasted the relationship and simultaneous changes in the financial markets during the crisis. Several fresh studies have used this approach (Li, Haneklaus, & Rahman, 2024; Younis et al., 2024; Yousaf, Youssef, & Gubareva, 2024). In contrast to conventional VAR models, which assume static relationships, TVP-VAR can highlight changes in dynamics that are essential for comprehending how markets behave during volatile periods. GARCH or fixed-parameter VAR may not have been as adaptable in capturing time-varying interactions. Third, the existing literature lacks evidence on how the COVID-19 and RU-war crisis influenced interconnectedness within or between DeFi assets, commodities, and Islamic stock markets. However, our study provides insightful information to stakeholders concerning DeFi assets and Islamic and commodity markets during these new crises using the advanced TVP-VAR approach.

The outcomes of this study reveal that all selected DeFi assets, commodities, and Islamic indices have positive mean returns, excluding livestock. Risk-spillover connectedness indicates that the commodity index is the highest net transmitter and the emerging markets index receiver's risk spillover in the system during the RU-war and the full sample. Similarly, return-spillover connectedness indicates that the ACWI index is the net transmitter and the emerging markets index receiver's risk spillover overall and, in the RU,-war. Further, livestock indices are net higher and significant risk-return spillover receivers in COVID-19. This study provides significant insights to investors, speculators, and decision makers, especially during crises.

Section 2 presents the literature, and Section 3 presents the methodology. Section 4 presents the study data and findings. Section 5 provides concluding remarks.

2. Literature review

A fundamental issue is how extreme market stress heightens the degree of risk transmission among markets due to the growing connectedness of financial markets worldwide. The literature indicates significant spillover effects among stocks, commodities, and Bitcoin (Bouri et al., 2021). As a result, an increasing number of researchers (Fasanya, Oliyide, Adekoya, & Agbatogun, 2021) have explored the functioning and interconnectedness of financial markets during the COVID-19. Financial markets worldwide, in specific regions and individual states, have been significantly harmed by the current COVID-19 outbreak and the RU-war.

Several studies show that there is more spillover between stock markets during times of crises. Theoretically, this leads to limited diversification gains, ultimately driving international investors to look for alternative investments such as gold and oil. (Ali et al., 2023) find that DeFi assets, palladium, aluminum, zinc, and nickel are net importers, while gold, silver, platinum, and copper are net exporters of return spillovers. Diversifying a metal-based COVID-19 portfolio using DeFi assets is advantageous. In contrast, a study of the dynamic transmission mechanism between the COVID-19 news sentiment (Google Trends Index), the S&P100, the crude oil volatility index, and the gold volatility index revealed that COVID-19 has a significant impact on the dynamic overall connectedness and that it is diverse over time (Apergis, Chatziantoniou, & Gabauer, 2023). Another study identified Google Trends, Ethereum, and Bitcoin and found that DeFi is an asset class distinct from other prominent cryptocurrencies (Corbet et al., 2022).

Notably, investors consistently experience worry about suffering losses in their assets during economic, financial, or health crises. As risk-averse and profit-maximizing investors typically sell their stocks or look for hedging assets in their investment portfolios, this anxiety frequently leads to intensive interactions across many markets. The digital assets can be used as a hedge against stock market declines and have a low correlation with financial and commodity markets(Cao & Xie, 2022; Guesmi, Saadi, Abid, & Ftiti, 2019). However, some recent studies on DeFi assets have identified diverse links with other assets, such as significant return spillovers inside and between marketplaces in the DeFi and cryptocurrency markets (Ugolini et al., 2023). Safe-haven assets are insignificant absorbers and transmitters of the spillover effects between markets. Similar findings were reported by Yousaf and Yarovaya (2022), who discovered that DeFi assets are unrelated to conventional asset classes. According to Piñeiro-Chousa et al. (2022), DeFi tokens act as a safe haven asset against the volatility of the stock market. According to Cevik et al. (2022), DeFi has the quality of safe-haven assets for markets in strategic commodities (crude oil and gold). Further, Umar, Aziz, and Tawil (2021) show that the financial markets, NFT, and DeFi became more interdependent, particularly during the pandemic crisis.

Conversely, due to Shariah laws, the Islamic stock market's conservative orientation may give it better durability (Akhtar & Jahromi, 2017). Some empirical studies also have linked the potential of Islamic equities to serve as safe havens to their fundamental characteristics, such as the prohibition of interest and risk transfer under the profit-and-sharing principle (Hassan, Hoque, & Gasbarro, 2019), low levels of leverage, and growing size. These characteristics make them resilient during volatile market periods and viable rivals to traditional equities to protect investors from various dangers, including those related to the crude oil market (Mensi, Selmi, & Al-Yahyaee, 2020). According to Rejeb (2017), traditional and Islamic financial markets are highly interdependent, indicating that Islamic financial assets do not provide a more substantial buffer against economic shocks than their conventional counterparts do.

Statistically, some empirical studies have explored the relationship between different commodities in economic shocks. Ji, Bouri, Roubaud, & Shahzad (2018) find that GARCH-copula models show increased systematic risk spillovers from energy to agricultural commodities in extreme downturns. Hammoudeh and Yuan (2008) reveal that leverage is only present in copper and gold and that silver volatility is inversely correlated with previous oil shocks. The addition of oil to a portfolio of copper and precious metals offers the benefit of diversity. According to Balcilar, Hammoudeh, and Asaba (2015), palladium and gold have little connection to other assets. There is only one cointegration connection between the six assets. Changes in the price of silver have little impact on the price of gold in the high-volatility regime, and palladium substantially influences both the exchange rate and oil prices in the low-volatility regime. According to Tiwari, Mukherjee, Gupta, and Balcilar (2019), the price of natural gas tended to be higher than that of oil before 2004. However, during the shale gas revolution (2007–2013), oil prices lagged behind natural gas prices. Their prices fluctuate cyclically because they are both "in-phase" prices.

Further studies found that the four precious metals are net transmitters of volatility spillover, while oil, titanium, steel, and silver are net receivers (Husain, Tiwari, Sohag, & Shahbaz, 2019). Oil, precious metals, titanium, and steel are only slightly affected by the S&P 500 index. Umar et al. (2021) conducted a TVP-VAR study investigating the dynamic return and volatility connectivity for the three most relevant agricultural and livestock commodity indices (Softs, Grains, and Livestock) and MCI. The analysis revealed that the MCI had the highest return and volatility values for most of the sample periods examined. According to Bakas and Triantafyllou (2020), COVID-19 has significantly affected the volatility of commodities markets and has a less significant but favorable impact on the gold market. However, the COVID-19 shock impacted the S&P GSCI energy index.

Few researchers have examined how the Islamic market interacted with other financial and commodity markets during the COVID-19 pandemic. Yarovaya, Elsayed, and Hammoudeh (2021) revealed that, in addition to Islamic bonds (Sukuk) behaving safely, an increased spillover between Islamic and conventional stock markets was observed during the COVID-19 era. Maghyereh, Abdoh, and Awartani (2019) looked at the dynamic relationships between gold, sukuk, and Islamic stocks and demonstrated that gold is a robust short-term diversifier of an Islamic portfolio. Sherif (2020) observed that the COVID-19 pandemic had a negative and minor effect on the Dow Jones faith-based Islamic index compared to its conventional UK counterpart for Islamic indices. Using the continuous wavelet coherence transform and windowed scalogram difference (WSD) methods, Boubaker and Rezgui (2020) examined the correlation between the DJIM Index and the prices of three commodities (oil, gas, and gold). They demonstrate a correlation between the DJIM and oil prices. However, it is less pronounced over time than the correlation between the DJIM and gas prices. Another study examined the dynamic return and volatility connectivity for six main industrial metals (tin, lead, nickel, zinc, copper, and aluminum) and the coronavirus media coverage index (MCI), revealing a significant increase during the pandemic's third wave (Umar, Polat, Choi, & Teplova, 2022).

Current research neglects the vital factors influencing volatility connections in DeFi assets, commodities, and the Islamic market. This gap prompts inquiries by stakeholders, underscoring the need to investigate drivers for informed decisions in portfolio and risk management, as well as enhancing stability in DeFi assets, commodities, and Islamic market interdependence during crises.

3. Data and methods

3.1. Data and statistics analysis

DeFi's exploration within this framework facilitates insights into portfolio optimization and risk mitigation. Commodity investments spanning energy, livestock, and metals are acknowledged for their potential to serve as inflation hedges, diversify portfolios, and yield substantial returns. Additionally, Islamic stocks have emerged as a distinctive element, exhibiting lower sensitivity to political uncertainty and greater stability during financial crises than conventional stocks. This multifaceted approach allows for a nuanced understanding of the dynamic relationships and risk factors of the studied financial landscape. The data selection covers multiple periods of crisis, such as the COVID-19 pandemic, the worldwide inflation spike in 2022, and geopolitical concerns, such as the confrontation between Russia and Ukraine. This period makes it possible to analyze the responses of various asset classes to crises, such as Islamic stocks, DeFi assets, and commodities, offering insights into their resilience and interdependencies. Several market behaviors create biases in financial data and are covered by strong econometric TVP-VAR modeling.

We selected these financial markets and assets for our study based on their higher market capitalization and significant influence on global financial markets, because they offer a wide range of investment possibilities and unique qualities that enable a thorough examination of market dynamics and risk distribution among established, developing, and moral asset classes. Furthermore, we investigate the benefits of interconnection and diversification under different economic conditions, especially during times of market stress. Our study uses daily data on DeFi assets (LINK, BAT MAKER) following (Ugolini et al., 2023), commodities (Energy, Precious Metals, Industrial Metals, Livestock, and Agriculture) following (Bahloul & Khemakhem, 2021), and Islamic stocks (ACWI, World, and EM) (Ahmed, 2019). We use three sample periods: Panel A = Dec 2019 to Mar 2023; Panel B = Jan 2020 to Dec 2020 (COVID-19); Panel C = Jan 2022 to Dec 2022 (RU-War). We used daily time-series data covering DeFi assets, commodities, and Islamic indices from December 2019 to March 2023. This period, marked by the onset of the COVID-19 pandemic and the emergence of the Russian-

Ukrainian conflict in 2022, facilitated a comprehensive examination of these dual crises.

From Dec 2019 to March 2023, the role of DeFi, commodity, and Islamic markets in our envisioned system changed due to the COVID's peak in 2021 and the RU-WAR in 2022.For example, In April 2022, the value of DeFi systems increased to $150bn USD, indicating a dynamic change in assets. This has sparked interest from policymakers and investors in digital financial markets, emphasizing the need to address concerns regarding DeFi assets. The Islamic financial sector has grown significantly in recent years, demonstrating resilience and becoming a significant part of the international financial system, surpassing its conventional counterparts during crises. We investigated the total returns index LINK, BAT MAKER, S&P GSCI Commodities, and their sub-indices, namely S&P GSCI Energy, S&P GSCI Precious Metals (PM), S&P GSCI Industrial Metals (IM), S&P GSCI Livestock, and S&P GSCI Agriculture. As for Islamic indices, we use the ACWI index, MSCI World (MSCI DM) and Emerging Market (MSCI EM) indices along with the world index. All data are obtained from the DataStream database and expressed in US dollars to obtain a homogeneous dataset, except for DeFi assets from coinmarketcap.com. Fig. 1 shows the volatility dynamics of the time-series plots of DeFi assets (LINK, BAT MAKER), commodities (Energy, Precious Metals, Industrial Metals, Livestock, and Agriculture), and Islamic stocks (ACWI, World, and EM).

Markowitz's theory suggests that investors might minimize portfolio risk by highlighting the significance of asset connectivity, whereby investments are dispersed among assets that move at different rates. According to the signaling theory, if signals cause linked responses across multiple assets, the benefits of diversification may be diminished. Furthermore, this research uses financial theories, such as Contagion Theory and Flight to Quality, to explain asset interconnections. According to the notion of contagion, people behave unreasonably while being hypnotized by others and imitating their actions. When investors move their asset allocation from riskier assets to safer ones, including stocks and bonds, it's known as a "flight to quality." This herd mentality is sometimes triggered by market volatility, such as crises, but can also result from smaller or targeted groups moving from risky to safer assets. The approach used in this study, TVP VAR, allows model parameters to vary over the years to capture spillover effects. This method identifies the times when market shocks, such as COVID and RU-WAR, have a major impact on other variables by reflecting the dynamic interactions and changing connections among them.

3.1.1. Returns statistics

We derive daily returns from the observed variables by computing $R_t = \ln(P_t/ P_{t-1})*100$ (Gupta & Gupta, 2023) based on daily price movements. Where ln is the natural log, and R_t is the return of daily prices of the selected index. P_t is the price of the selected index at time t and P_{t-1} is the price chosen at the first lag. Table 1 reports the descriptive statistics of the daily returns over the sample period. Panel A (full sample) indicates that DeFi assets, commodities, and Islamic indices have positive mean returns, excluding livestock (i.e., −0.006). The highest mean returns were recorded for LINK (0.064) followed by Islamic EM (0.05). The highest variances were recorded for all the DeFi assets. Similarly, in Panel B (COVID-19), all indices indicate a positive mean return, except for livestock, energy, and commodities. The highest mean of returns is for the LINK index (0.311), followed by MAKER (0.48), whereas the highest variance is for DeFi assets. Conversely, in Table 1 Panel C (RU-WAR), the highest mean of returns is for the energy index, followed by the commodity indices. By contrast, the highest negative values are for DeFi assets and the Islamic EM index. The DeFi assets have the highest variance in panel C (RU-WAR). These findings are similar to (Ali et al., 2023). The Jarque–Bera statistic test, which analyzes both the kurtosis and skewness of time-series data, is highly significant. The skewness of the all-time series is positive; at Q2 (10), all index values are significant, excluding the world and Islamic indices.

3.1.2. Volatilities statistics

The daily volatility of the variables was calculated using the GARCH (1,1) model (Younis, Yousaf, Shah, & Longsheng, 2023). Table 2 reports the descriptive statistics of the volatilities for the sample period. Panel A (full sample) indicates that all DeFi assets, commodities, and Islamic indices have positive average volatility. The highest average volatilities were recorded for MAKER (13.23), followed by LINK (11.16) and BAT (0.05). Meanwhile, the highest variances were recorded for all DeFi assets. Similarly, in Panel B (COVID-19), all indices indicate positive average volatilities, whereas the highest average volatilities are recorded for MAKER (16.146), followed by LINK (12.6) and BAT (9.9). The highest variance is observed for DeFi assets. Consequently, all the

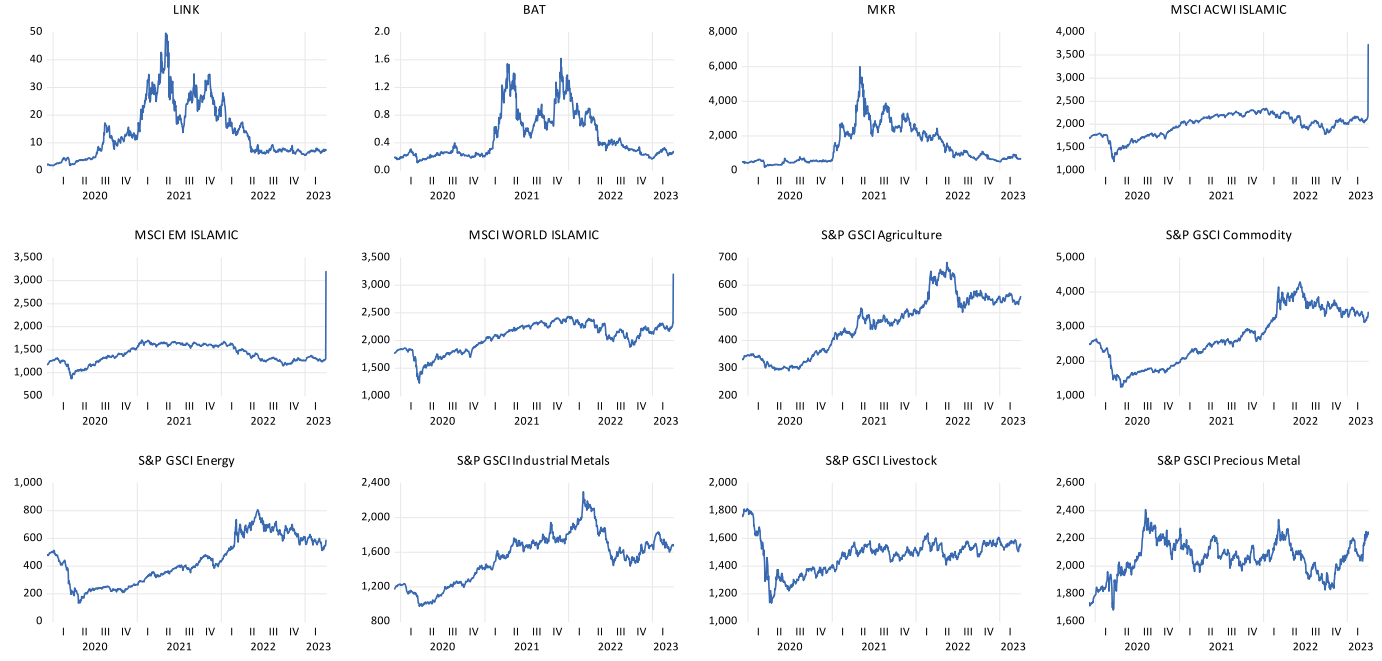

Fig. 1. Time Series Plots price level of Defi, commodities and Islamic stock markets.

Table 1
Summary of Return Statistics and preliminary analysis.

	LINK	BAT	MKR	Livestock	Commodity	Energy	Precious. Metal	Industrial. Metals	Agriculture	ACWI	WORLD	EM
Panel A: Overall Sample												
Mean	0.064	0.033	0.015	−0.006	0.016	0.01	0.013	0.018	0.026	0.039	0.03	0.05
Variance	10.09	9.371	11.154	0.232	0.574	1.676	0.247	0.294	0.294	0.871	0.495	2.022
Skewness	−1.280***	−0.659***	−1.411***	−0.613***	−1.326***	−1.925***	−0.356***	−0.113	−0.189**	17.850***	8.260***	23.930***
Ex.Kurtosis	9.668***	7.837***	26.562***	4.939***	8.655***	19.961***	3.991***	1.023***	2.062***	449.003***	172.717***	655.870***
JB	3613***	2281***	25774***	935***	2959***	14929***	593***	39.62***	158.8***	73289***	1087503***	15622471***
ERS	−8.723***	−9.186***	−12.726***	−10.503***	−9.127***	−9.542***	−4.572***	−5.966***	−12.887***	−2.970***	−4.548***	−2.196**
Q(10)	14.322***	15.518***	34.495***	17.443***	8.473	11.531**	9.263*	4.984	11.618**	5.335	16.072***	0.809
Q2(10)	50.316***	19.247***	48.463***	924.796***	102.362***	78.409***	59.345***	27.951***	103.175***	0.002	0.217	0
Panel B: COVID-19												
Mean	0.311	0.007	0.048	−0.041	−0.045	−0.103	0.034	0.023	0.023	0.017	0.013	0.033
Variance	12.004	9.048	14.586	0.473	0.837	3.331	0.384	0.178	0.166	0.468	0.525	0.438
Skewness	−1.923***	−2.274***	−3.852***	−0.510***	−1.662***	−1.869***	−0.337**	−0.519***	−0.032	−1.259***	−1.207***	−0.682***
Ex.Kurtosis	16.888***	18.705***	47.347***	2.631***	9.953***	14.552***	3.625***	0.671**	0.845**	10.000***	9.926***	4.175***
JB	3274.890***	4045.264***	25,120.510***	86.943***	1202.157***	2464.308***	148.395***	16.666***	7.832**	1160.950***	1139.232***	210.621***
ERS	−4.954***	−3.014***	−6.485***	−6.324***	−5.994***	−6.119***	−7.895***	−5.920***	−7.261***	−5.209***	−5.471***	−4.270***
Q(10)	13.413**	23.825***	27.716***	9.777*	3.913	5.364	11.725**	4.462	6.356	35.381***	40.768***	14.152***
Q2(10)	11.334**	5.216	15.689***	276.709***	30.649***	19.058***	24.652***	12.628**	5.244	113.081***	118.112***	182.681***
Panel C: Russian-Ukraine War												
Mean	−0.238	−0.337	−0.258	0.009	0.038	0.057	0.002	−0.013	0.02	−0.023	−0.02	−0.042
Variance	7.596	6.513	7.734	0.147	0.69	1.335	0.196	0.428	0.425	0.227	0.266	0.236
Skewness	−0.919***	−0.748***	0.086	−0.315**	−0.594***	−0.578***	0.084	0.21	−0.213	0.067	0.072	0.012
Ex.Kurtosis	3.339***	3.063***	3.844***	0.47	2.567***	2.580***	0.582*	0.640*	0.969**	0.47	0.630*	1.715***
JB	157.410***	125.860***	160.415***	6.681**	86.650***	86.560***	3.975	6.356**	12.136***	2.59	4.525	31.870***
ERS	−7.458***	−8.059***	−5.938***	−2.477**	−5.309***	−6.612***	−3.318***	−4.275***	−2.378**	−5.325***	−6.026***	−3.126***
Q(10)	5.625	8.643	6.531	7.458	11.817**	13.117**	5.73	3.997	7.016	16.641***	10.727**	6.992
Q2(10)	27.247***	42.549***	10.778**	4.874	46.015***	49.094***	3.016	4.212	50.760***	10.716**	6.697	4.049

Note: This table presents return summary statistics of Defi, commodities and Islamic stock markets for COVID-19 (Jan, 20 to Dec, 20), Russia-Ukraine war (Jan, 22 to Dec, 22) and full sample (Dec, 19 to Mar 2023). ***, **, * denote significance at 1 %, 5 % and 10 % level. Skewness: D'Agostino (1970) test; Kurtosis: Anscombe and Glynn (1983) test; JB: Jarque and Bera (1980) normality test; ERS: Stock et al. (1996) unit-root test; Q(10) and Q2(20): Fisher and Gallagher (2012) weighted Portmanteau test are reported.

Table 2
Summary of Volatility Statistics and preliminary analysis.

	LINK	BAT	MKR	Livestock	Commodity	Energy	Precious. Metal	Industrial. Metals	Agriculture	ACWI	WORLD	EM
Panel A: Overall Sample												
Mean	11.16	10.08	13.23	0.21	0.569	1.745	0.245	0.301	0.297	1.142	0.696	1.288
Variance	190.401	78.717	637.208	0.059	0.402	10.675	0.016	0.013	0.036	15.228	4.322	1.502
Skewness	7.810***	5.703***	10.74***	4.534***	3.998***	5.529***	4.141***	1.182***	2.024***	12.236***	11.091***	1.278***
Ex.Kurtosis	81.78***	50.43***	140.1**	21.54***	18.691***	37.294***	24.44***	1.505***	4.037***	191.6***	161.1***	1.007***
JB	25044***	96586***	726172***	19731***	14929***	54661***	24069***	283.5***	1180***	13484***	95614***	272.8***
ERS	−8.500***	−7.929***	−8.462***	−3.977***	−4.684***	−5.509***	−5.653***	−4.452***	−3.705***	−7.402***	−7.492***	0.777
Q(10)	1074***	1357***	1196***	4194***	2870***	2449***	2310***	3343***	3764***	927.4***	1339***	4508***
Q2(10)	511.5***	650.9***	684.5***	3779***	1916***	1116***	1751***	3116.811***	3303***	222.1***	302.8***	4258***
Panel B: COVID-19												
Mean	12.568	9.87	16.146	0.36	0.762	3.216	0.305	0.218	0.192	2.167	1.299	0.896
Variance	394.893	145.609	1847.778	0.16	0.96	30.111	0.037	0.004	0.003	45.749	12.968	1.012
Skewness	6.751***	6.186***	6.933***	2.189***	2.644***	3.035***	2.627***	1.519***	0.992***	7.298***	6.547***	1.362***
Ex.Kurtosis	52.350***	45.131***	51.612***	3.856***	6.521***	10.118***	8.629***	3.195***	1.196***	64.103***	53.062***	0.022
JB	31,907.527***	23,906.343***	31,178.658***	371.616***	769.416***	1519.698***	1114.093***	212.226***	58.618***	47,184.499***	32,607.774***	80.966***
ERS	−4.699***	−4.696***	−4.473***	−2.163**	−2.346**	−2.866***	−2.297**	−2.245**	−2.047**	−3.867***	−3.955***	−0.239
Q(10)	281.587***	376.676***	355.351***	1248.259***	837.987***	684.922***	722.245***	871.396***	805.788***	273.573***	396.206***	1367.124***
Q2(10)	152.415***	186.726***	204.455***	1121.363***	545.629***	306.841***	501.838***	842.202***	768.031***	64.353***	87.066***	1359.694***
Panel C: Russian-Ukraine War												
Mean	9.619	8.269	10.289	0.154	0.645	1.428	0.223	0.392	0.398	1.133	0.695	1.746
Variance	62.911	26.756	58.878	0.001	0.233	1.512	0.003	0.016	0.054	2.677	0.672	0.349
Skewness	3.413***	2.889***	2.968***	1.154***	2.557***	2.976***	1.424***	0.709***	1.266***	3.794***	3.420***	0.850***
Ex.Kurtosis	13.582***	9.485***	10.203***	0.790**	8.255***	11.476***	2.480***	0.128	0.802**	19.129***	15.028***	−0.597***
JB	2503.225***	1336.315***	1509.360***	64.457***	1021.619***	1810.374***	154.531***	21.978***	76.425***	4587.976***	2953.509***	35.159***
ERS	−2.021**	−4.424***	−4.043***	−2.417**	−2.054**	−2.225**	−3.805***	−1.866*	−1.886*	−4.449***	−4.144***	4.451
Q(10)	381.178***	467.318***	333.179***	739.521***	893.927***	839.442***	414.058***	769.504***	1044.871***	130.745***	155.574***	1291.951***
Q2(10)	205.822***	345.685***	193.638***	681.235***	608.222***	511.483***	406.480***	748.176***	935.115***	64.633***	82.684***	1254.829***

This table presents volatility summary statistics of Defi, commodities and Islamic stock markets for COVID-19 (Jan, 20 to Dec, 20), Russia-Ukraine war (Jan, 22 to Dec, 22) and full sample (Dec, 19 to Mar 2023). ***, **, * denote significance at 1 %, 5 % and 10 % level. Skewness: D'Agostino (1970) test; Kurtosis: Anscombe and Glynn (1983) test; JB: Jarque and Bera (1980) normality test; ERS: Stock et al. (1996) unit-root test; Q(10) and Q2 (20): Fisher and Gallagher (2012) weighted Portmanteau test are reported.

indices have positive average volatilities, and the highest volatilities and variance are recorded for DeFi assets in panel C (RU-WAR) (Table 2). The Jarque–Bera statistic test, which analyzes both the kurtosis and skewness of time-series data, is highly significant. The skewness of the all-time series is positive; in Q2 (10), all index values are significant.

3.2. Econometric modeling framework

The foundational concept underpinning the theory of connectedness in financial markets emanates from recognizing that diverse financial market assets encompassing commodities, macroeconomic indicators, and equities are not insular entities, but are intricately linked. This interconnectedness is attributed to the economic determinants, investor sentiment, and overarching market trends. Moreover, these variables exhibit an inherent correlation with historical trajectories. Comprehending the interrelationships and correlations among distinct assets empowers investors to enhance decision-making acumen, effectively manage risks, and adeptly navigate the intricate dynamics inherent in the financial landscape. To elucidate this theory, our study employs Time-Varying Parameter-Vector Autoregressive (TVP-VAR) analysis to discern and explain the dynamic connectedness inherent in the studied variables.

3.2.1. TVP-VAR framework

The conventional comprehension of linkages within financial systems, relying on simplistic correlations and associated metrics, proves inadequate for elucidating the systemic dynamics intrinsic to the intricate networks characterizing financial markets (Kumar et al., 2022). Following the methodology proposed by (Diebold & Yilmaz, 2012), our investigation focuses on assessing the interconnections among DeFi assets, commodities, and the Islamic stock market. This exploration is conducted by applying the generalized TVP-VAR framework coupled with implied forecast error variance decompositions. The TVP-VAR model assumes that the parameters are dynamic and can change over time due to policy changes, economic changes, or structural breaks. The first assumption in the VAR specification follows a first-order random-walk process, allowing for both temporary and permanent parameter shifts. Second, the TVP-VAR model is based on a stochastic volatility process, as the parameters do not have homogeneity due to external shocks that change over time, such as COVID-19 and the Russian-Ukraine war, resulting in different variances (Nakajima, 2011). Because of the flexibility of the TVP VAR model, findings are obtained with more accuracy, reliable conclusions, and a better understanding of the relationship between DeFi assets, commodities, and Islamic stock indicators throughout a range of periods. These analyses yield a numerical spillover score within a system of variables that serves as a proxy for systemic risk. The advantage of the TVP-VAR approach is that it removes the burden of the frequently arbitrary rolling window size, which may result in extremely unpredictable or flattened parameters and loss of important observations. Additionally, this strategy can be used to investigate dynamic connectivity using time-series data (Younis et al., 2024).

The literature often uses GARCH models to analyze price volatility, providing insights into time-series volatility and conditional correlations. Nevertheless, a comprehensive mechanism for detecting volatility dynamics and structural changes is absent in these models. Multivariate GARCH models often struggle with the convergence of optimization algorithms and determine the exact influence of variables from other factors or their histories. The TVP-VAR methodology addresses this limitation by addressing the limitations of GARCH models. This study generalizes VAR models to analyze the stochastic time-varying volatilities in volatility shocks. It provides a new perspective on the transmission of shocks between DeFi, commodities, and Islamic markets, and explores the impact of independent shocks on volatility. TVP-VAR is a statistical model that permits variable associations to change over time, hence enabling the assessment of dynamic interconnectivity This empirical technique was chosen since it has several benefits. The Kalman filter estimation technique allows for the variation of variances over time by utilizing decay factors. Thus, to be more precise, this pragmatic method does not lessen the observations we made. Additionally, the existence of an anomaly would not materially alter our findings, and this strategy offers a more accurate correction for parameter variations. Our approach's key component is calculating net paired connectivity, which identifies the transmission pathways between DeFi, commodities, and Islamic markets.

The TVP-VAR model in the time-frequency framework using the filtered series was obtained from the j-level multi-resolution decomposition. The TVP-VAR strategy can be expressed as.

$$y_t = \beta_t z_{t-1} + \in_t; \in_t | F_{t-1} \sim N(0, S_t) \tag{1}$$

$$vec(\beta_t) = vec(\beta_{t-1}) + v_t; v_t | F_{t-1} \sim N(0, R_t) \tag{2}$$

where y_t and $z_t = \left[y_{t-1}, \ldots, y_t - p\right]'$ represent $N \times 1$ and $P \times 1$ dimensional vectors, respectively. β_t is an $N \times N_p$ dimensional time-varying coefficient matrix and ϵ_t is an $N \times 1$ dimensional error disturbance vector with an $N \times N$ time-varying variance-covariance matrix S_t, $vec(\beta_t)$ and $v_t$are $N_p^2 \times 1$ dimensional vectors and R_t is an $N_p^2 \times N_p^2$ dimensional matrix. The generalized impulse response function (GIRF) and generalized forecast error variance decomposition (GFEVD) were then calculated using the vector moving average (VMA) model of the VAR system (Koop, Pesaran, & Potter, 1996; Pesaran & Shin, 1998) as follows:

$$y_t = \sum_{j=0}^{\infty} L' W_t^j L \in_{t-j} \tag{3}$$

$$y_t = \sum_{j=0}^{\infty} A_{it} \in_{t-j} \tag{4}$$

where $L = \left[I_N, \ldots, 0_p\right]'$ is an $N_p \times N$ dimensional matrix, $W = \left[\beta t; I_{N(p-1),}\ 0_{N(p-1)\times N}\right]$ is an $N_p \times N_p$ dimensional matrix, and $A_{it}$is an $N \times N$ dimensional matrix. GIRFs show how each variable responds to a shock in variable i. The differences between a J-step-ahead forecast are computed twice: once for when variable i is shocked and once for, where variable i is not shocked because of the lack of a structural model. This discrepancy is to be caused by a shock in the variable i; hence it is calculated by.

$$GIRF_t\left(K, \delta_{j,t} F_{t-1}\right) = E\left(y_{t+K} | \in_{j,t} = \delta_{j,t} F_{t-1}\right) - E(Y_{t+K} | F_{t-1}) \tag{5}$$

$$\psi_{j,t}^g(K) = \frac{A_{K,t} S_t \in_{j,t}}{\sqrt{S_{jj,t}}} \frac{\delta_{j,t}}{\sqrt{S_{jj,t}}} \delta_{j,t} = \sqrt{S_{jj,t}} \tag{6}$$

$$\psi_{j,t}^g(K) = \frac{A_{K,t} S_t \in_{j,t}}{\sqrt{S_{jj,t}}} \tag{7}$$

where$\psi_{j,t}^g$represents the GIRFs of variable j and K represents the forecast horizon, $\delta_{j,t}$ theselection vector with one on the jth position and zero otherwise, and F_{t-1} the information set until t–1. Then, the GFEVD, or the variance share of one variable over others, can be calculated as follows:

$$\widetilde{\Phi}_{\mathrm{ij,t}}^{\mathrm{g}}(\mathrm{K}) = \frac{\sum_{\mathrm{t=1}}^{\mathrm{K-1}} \psi_{\mathrm{j,t}}^{2.g}}{\sum_{\mathrm{j=1}}^{\mathrm{N}} \sum_{\mathrm{t=1}}^{\mathrm{K-1}} \psi_{j,t}^{2.g}}; \sum_{j=1}^{N} \widetilde{\Phi}_{ij,t}^{g}(\mathrm{K}) = 1 \; and \sum_{j=1}^{N} \mathrm{N}_{ij,t}^{g}(\mathrm{K}) = \mathrm{N} \tag{8}$$

Based on Eq. (8), the total connectivity index, which may be created as follows, can be used to investigate how a stock market in one index affects another index.

$$C_t^g(K) = \frac{\sum_{i,j=1\ i \neq j}^{N} \widetilde{\Phi}_{ij,t}^{g}(\mathrm{K})}{\mathrm{N}} * 100 \tag{9}$$

The analysis of directional connectivity is intriguing. Three elements

of this direction are taken into account by the procedure under consideration: In the beginning, total directed connectivity to others is described as

$$C^{g}_{i\rightarrow j,t}(K)=\frac{\sum_{i,j=1\ i\neq j}^{N}\widetilde{\Phi}^{g}_{ij,t}(\mathrm{K})}{\sum_{i,j=1}^{N}\widetilde{\Phi}^{g}_{ij,t}(\mathrm{K})}*100 \tag{10}$$

Second, total directional connectedness *from others,* given as

$$C^{g}_{i\leftarrow j,t}(K)=\frac{\sum_{i,j=1\ i\neq j}^{N}\widetilde{\Phi}^{g}_{ij,t}(\mathrm{K})}{\sum_{j=1}^{N}\widetilde{\Phi}^{g}_{ij,t}(\mathrm{K})}*100 \tag{11}$$

The net total directional connectedness can then be calculated by subtracting Eq. (16) from Eq. (11), as follows:

$$C^{g}_{i,t}(K)=C^{g}_{i\rightarrow j,t}(K)-C^{g}_{i\leftarrow j,t}(K) \tag{12}$$

Table 3
Averaged Return Statistics Connectedness.

	LINK	BAT	MKR	Livestock	Commodity	Energy	Precious. Metal	Industrial. Metals	Agriculture	ACWI	WORLD	EM	FROM
Panel A: Overall Sample													
LINK	40.86	21.17	18.2	0.87	1.14	0.82	0.78	1.89	0.66	5.75	5.98	1.9	59.14
BAT	20.87	42.03	15.43	0.98	1.52	1.12	1.02	1.65	0.74	6.17	6.45	2.02	57.97
MKR	18.99	16.6	43.92	0.43	1.37	1.03	0.86	1.54	0.93	6.1	6.48	1.75	56.08
Livestock	1.23	1.64	0.74	75.56	3.27	1.66	1.07	1.25	2.96	4.22	4.22	2.16	24.44
Commodity	1.01	1.22	1.11	1.44	31.02	29.42	2.27	7.23	8.09	6.77	6.62	3.82	68.98
Energy	0.8	1.02	0.94	0.87	33.54	35.41	1.56	5.16	4.91	6.26	6.17	3.36	64.59
Precious. Metal	1.61	2.05	1.56	1.16	4.53	2.68	65.89	5.18	3.35	4.81	4.74	2.43	34.11
Industrial. Metals	2.17	1.77	1.55	0.68	10.29	6.47	3.83	44.39	4.23	9.09	8.57	6.97	55.61
Agriculture	1.05	1.01	1.38	1.81	14.42	7.88	2.79	5.4	55.44	3.12	2.87	2.83	44.56
ACWI	4.51	4.39	4.58	1.47	5.65	4.53	2.26	4.98	1.52	27.04	26.46	12.62	72.96
WORLD	4.73	4.75	4.97	1.47	5.72	4.64	2.22	4.85	1.41	27.59	28.37	9.29	71.63
EM	3.34	2.75	2.91	1.3	5.02	3.84	2.38	5.82	2.16	20.33	15.53	34.62	65.38
TO	60.3	58.36	53.37	12.46	86.48	64.09	21.05	44.93	30.94	100.23	94.09	49.15	675.46
Inc.Own	101.15	100.39	97.29	88.01	117.5	99.51	86.94	89.32	86.38	127.27	122.46	83.77	TCI
NET	1.15	0.39	−2.71	−11.99	17.5	−0.49	−13.06	−10.68	−13.62	27.27	22.46	−16.23	56.29
NPDC	6	7	5	1	9	8	0	3	2	11	10	4	
Panel B: COVID-19													
LINK	34.58	18.26	17.49	1.75	2.5	1.73	1.74	2.64	1.66	7.09	7.49	3.06	65.42
BAT	16.57	34.76	14.98	1.46	2.84	2.01	2.43	1.81	1.6	8.66	9.07	3.8	65.24
MKR	17.94	16.8	38.24	0.59	2.21	1.59	1.45	1.67	2.07	7.21	7.78	2.45	61.76
Livestock	2.3	2.64	0.96	64.42	4.09	2.23	1.51	1.23	6.61	5.38	5.45	3.17	35.58
Commodity	2.16	2.53	1.78	1.61	28.75	27.59	1.13	5.17	6.52	8.52	8.37	5.88	71.25
Energy	1.67	2	1.45	0.69	31.66	33.07	0.64	4.27	4.67	7.47	7.39	5.03	66.93
Precious. Metal	3.75	5.14	3.37	2.13	3.42	2.03	67.12	0.63	1.96	4.21	4.43	1.81	32.88
Industrial. Metals	3.19	2.07	1.68	0.81	8.02	6.03	0.48	42.63	2.33	11.28	10.39	11.07	57.37
Agriculture	2.71	2.47	2.83	4.08	11.69	8.12	1.1	2.85	48.19	5.38	4.91	5.66	51.81
ACWI	4.92	6.04	5.21	1.99	6.81	5.12	1.62	6.06	2.74	22.67	22.35	14.46	77.33
WORLD	5.38	6.62	5.95	2.01	6.73	5.09	1.61	5.72	2.49	22.96	23.3	12.13	76.7
EM	2.66	3.25	1.96	2.01	7.42	5.51	2	7.88	4.12	18.85	15.69	28.65	71.35
TO	63.25	67.82	57.67	19.15	87.39	67.04	15.71	39.94	36.78	107.02	103.32	68.54	733.63
Inc.Own	97.83	102.59	95.9	83.57	116.13	100.11	82.83	82.57	84.97	129.69	126.62	97.18	TCI
NET	−2.17	2.59	−4.1	−16.43	16.13	0.11	−17.17	−17.43	−15.03	29.69	26.62	−2.82	61.14
NPDC	5	6	4	1	9	8	1	3	2	11	10	6	
Panel C: Russian-Ukraine War													
LINK	35.64	23.39	17.77	0.63	0.35	0.3	0.8	1.46	0.13	8.82	8.96	1.76	64.36
BAT	23.46	35.61	17.31	1.48	0.65	0.57	0.82	1.84	0.22	8.18	8.44	1.43	64.39
MKR	19.24	18.55	37.91	0.39	0.72	0.57	0.84	1.56	0.63	8.74	8.83	2.01	62.09
Livestock	1.23	2.48	1.27	78.39	2.12	1.58	1.78	1.83	0.53	3.79	3.68	1.33	21.61
Commodity	0.41	0.53	0.99	1.23	30.18	29.41	6.54	9.63	12.04	3.57	3.26	2.2	69.82
Energy	0.38	0.51	1.02	1.4	32.28	33.21	5.68	7.71	8.98	3.4	3.07	2.36	66.79
Precious. Metal	0.92	0.92	1.08	1.23	10.51	8.31	47.95	9.48	7.34	5.06	4.75	2.46	52.05
Industrial. Metals	1.88	2.01	1.97	0.97	12.02	8.67	7.42	38.29	7.43	7.58	7.02	4.72	61.71
Agriculture	0.32	0.23	0.78	0.39	19.09	13.25	7.47	8.4	45.77	1.64	1.53	1.14	54.23
ACWI	8.39	7.25	8.78	1.59	2.15	1.96	1.65	3.45	0.32	28.62	28.36	7.49	71.38
WORLD	8.54	7.54	8.7	1.56	2.09	1.9	1.64	3.11	0.32	29.49	30.16	4.93	69.84
EM	7.12	5.54	8.36	1.37	1.85	1.76	1.47	4.81	0.36	19.54	17.05	30.77	69.23
TO	71.88	68.95	68.03	12.24	83.84	68.28	36.1	53.27	38.3	99.81	94.94	31.85	727.5
Inc.Own	107.52	104.56	105.94	90.63	114.03	101.49	84.05	91.56	84.07	128.43	125.11	62.62	TCI
NET	7.52	4.56	5.94	−9.37	14.03	1.49	−15.95	−8.44	−15.93	28.43	25.11	−37.38	60.63
NPDC	9	6	8	1	6	5	2	4	1	10	10	4	

Note: This table presents the estimations of the static returns connectedness between Defi, commodities and Islamic stock markets for COVID-19 (Jan, 20 to Dec, 20), Russia-Ukraine war (Jan, 22 to Dec, 22) and full sample (Dec, 19 to Mar 2023).

It is important to note that Eq. (13) shows how stock prices affect the analysis network. Therefore, a positive value of Eq. (13) indicates that the network influences stock prices in index i more than the reverse is true, while a negative value indicates that the network drives stock prices in index i. To further explore bidirectional linkages, the following formula is used to compute the net pairwise directional connectedness (NPDC):

$$\mathrm{NPDC}_{\mathrm{i,j}}(\mathrm{K}) = \widetilde{\Phi}^{g}_{ij,t}(\mathrm{K}) - \widetilde{\Phi}^{g}_{ji,t}(\mathrm{K}) \tag{13}$$

According to Eq. (13), a positive NPDC value means that stock values in index i are dominated by those in index j, whereas a negative NPDC value implies the opposite.

4. Results and discussion

We present the findings of our empirical investigation. The average volatility connectedness estimation follows the average return connectedness measure estimates (i.e., the average estimate across the full sample duration). In addition to examining overall interconnectedness on a global scale, we scrutinize the specific linkages between assets within distinct investment horizons. It should be highlighted that, for the sake of clarity, the discussion will be mostly centered on the conclusions we obtain for net directional and total connectedness, especially for the periods of COVID-19 and the RU-war. In doing so, we narrow the scope of our study to what might be a key element in the current literature, namely, to further illuminate the recent dynamic interconnection of DeFi assets, commodities, and Islamic stock markets to provide further evidence about these stock indexes.

4.1. Average return connectedness

DeFi assets, S&P GSCI commodities, and developed and emerging Islamic indices' total spillover index matrices of return connectedness are shown in Table 3 for the complete sample, the COVID-19 crisis period, and the RU-war, respectively. The total spillover index matrices of returns connectedness among DeFi assets, S&P GSCI commodities, and both developed and emerging Islamic indices are presented in Panel A of Table 3 for the complete sample period from 2019 to 2022. The total connectedness index (TCI) in panel A equals 56.29 %, indicating the significance of connectivity during this period. The subsamples of COVID-19 (TCI = 61.14 %) and the RU-war (TCI = 60.63 %) also demonstrate the importance of connectivity during this period, which means that more than half of the variance in the volatility forecast is attributable to crisis spillover in these stock prices. Table 3 refers to penals A, B, and C; the ACWI (27.27 %, 29.69 %, and 28.43 %, respectively) index is the net higher and significant risk transmitters spillovers followed by the MSCI World and Commodities indices in the system during the full sample as well as in the COVID-19 and RU-war samples. Similarly, the net higher and significant risk spillover receivers are EM (−16.23 % and − 37.38 %), followed by agriculture and precious metals in the full sample and RU-war, respectively. Livestock (−16.43 %), precious metals (17.17 %), and industrial metals (−17.43 %) are the net higher risks of spillover revivers during COVID-19, consistent with (Piñeiro-Chousa et al., 2022; Younis et al., 2024).

Several intriguing discoveries can be observed in Table 3, which presents the average connectivity for the entire data period. The forecast error variance is first explained by these stock indices. For instance, the system's stock indices ACWI, MSCI World, and Commodities index efficiently separate the directional connectivity variance by more than 55 %, indicating that more than half of the variance in the volatility forecast is attributable to these stock indices. Second, these stock indices are the most important transmitters of inter-connectedness shocks, reflecting risk spillovers and return connectedness during crisis episodes. The ACWI index is the net higher and significant transmitter and EM index receiver risk spillover in the system during full and RU-war samples. Further, livestock indices are net higher and significant risk spillover receivers in COVID-19. These stock indices, ACWI, Commodities, WDI, and EM explain more than 75 % of the variance in these crisis episodes. These findings are similar to those of previous studies in terms of cross-market dynamics analysis of diverse crises (Ali et al., 2023; Apergis et al., 2023).

4.2. Average volatilities connectedness

The total spillover index matrices showing the connectedness of volatilities between DeFi assets, S&P GSCI commodities, and both developed and emerging Islamic indices for the complete sample, the COVID-19 crisis period, and the RU-war are shown in Table 4. As shown by the total connectedness index (TCI) in Penal A, which is equal to 54.78 %, as well as the subsamples of COVID-19 (TCI = 64.93 %) and the RU-war (TCI = 62.52 %), more than half of the variance in the volatility forecast is attributable to crisis spillover in these stock prices. Table 4 indicates that in penals A, B, and C, the Commodities (23.1 % and 46.93 %) index is the net higher and significant risk transmitters spillovers, followed by World and ACWI indices in the system during the full sample as well as in COVID-19. The ACWI (38.3 %) index is the net higher and significant risk transmitter spillover, followed by the world (34.22) and livestock indices (23.76 %) in the RU-war. Similarly, the net higher and significant risk spillover receivers are EM (−30.15 % and − 47.45 %) in the full sample and the RU-war, respectively, while livestock (−47.27 %) is the net higher risk spillover reverse during COVID-19. A study found similar results in the case of DeFi, finding that DeFi assets, palladium, aluminum, zinc, and nickel are net importers (Ali et al., 2023).

Table 4 shows that these stock indices largely explain the forecast error variance. For instance, the system's stock indices, commodities, World and ACWI index efficiently separate the directional connectivity variance by more than 55 %, indicating that more than half of the variance in the volatility forecast is attributable to these stock indices. Furthermore, these stock indices are the most important transmitters of inter-connectedness shocks, reflecting risk spillovers and return connectedness during crisis episodes. The commodities index is the net higher and significant transmitter and the EM index receiver's risk spillover in the system during the full and RU-war samples. Further, livestock indices are net higher and significant risk spillover receivers in COVID-19. Finally, the stock indices Commodities and WDI, ACWI, and EM explain more than 75 % of the variance in these crisis episodes. This study's outcomes are similar to the previous studies' outcomes (Bahloul & Khemakhem, 2021; Bakas & Triantafyllou, 2020; Cao & Xie, 2022; Chowdhury, Abdullah, Alam, Abedin, & Shi, 2023). The researchers' findings also reveal that total connectedness exhibits temporal heterogeneity that is notably influenced by crises. Moreover, their investigation highlighted heightened spillover transmission, particularly during the COVID-19 pandemic and the RU-War. The results further underscore the robust and moderate levels of volatility connectedness within commodity networks. The findings demonstrate a high degree of interdependence and dependence among these stock indices in the system, which is reflected in the high average values of total and directional spillovers across regions during the study period.

4.3. Dynamic average and net return-volatility connectedness

To fully understand spillovers, particularly during crucial moments, we examine the time-varying behavior of interconnections among DeFi assets, commodities stocks, and Islamic equities. The connection between total net return, volatility, risks, and spillovers is shown in Fig. a. Fig. 2b (COVID-19) shows the total return (blue line) and volatility (orange line) connectedness of all the selected stock markets are going to increase and decrease in the first four months and then consistently decrease due to COVID-19 significant risks spikes effect. This means that, first, it is transmitter/receivers, and, finally, consistent net

Table 4
Averaged Volatility Statistics Connectedness.

	LINK	BAT	MKR	Livestock	Commodity	Energy	Precious. Metal	Industrial. Metals	Agriculture	ACWI	WORLD	EM	FROM
Panel A: Overall Sample													
LINK	31.73	19.41	14.75	0.48	2.1	1.48	0.79	2.57	1.35	11.62	11.99	1.72	68.27
BAT	21.66	34.28	12.92	0.4	2.31	1.6	0.65	2.13	1.05	10.48	10.81	1.69	65.72
MKR	17.75	14.77	25.44	0.61	2.84	2.07	0.91	2.16	1.39	14.6	15.35	2.11	74.56
Livestock	1.77	1.71	3.57	63.68	4.58	3.42	2.77	2.86	5.18	4.23	4.06	2.17	36.32
Commodity	0.4	0.66	0.27	1.66	43.68	38.39	1.69	2.43	3.03	3.29	3.17	1.31	56.32
Energy	0.26	0.44	0.23	1.71	42.39	45.54	1.56	1.61	1.47	2.04	1.97	0.77	54.46
Precious. Metal	1.39	1.2	1.21	4.02	3.52	3.39	69.71	4.33	2.02	2.83	2.93	3.44	30.29
Industrial. Metals	1.47	1.43	0.72	4.93	5.36	3.44	4.02	61.57	8.5	3.18	3.16	2.21	38.43
Agriculture	1.87	1.8	1.98	4.84	4.73	2.58	3.05	5.94	67.98	2	2.28	0.94	32.02
ACWI	10.32	8.8	11.91	0.49	3.95	2.42	1.15	2.24	1.13	26.92	26.27	4.39	73.08
WORLD	10.26	8.76	11.85	0.47	4.45	2.78	1.41	2.35	1.26	25.73	26.88	3.8	73.12
EM	3.51	4.03	3.28	3.61	3.19	2.62	4.84	9.39	4.81	7.95	7.49	45.28	54.72
TO	70.66	63.03	62.69	23.22	79.42	64.19	22.85	38.02	31.2	87.96	89.49	24.56	657.3
Inc.Own	102.4	97.31	88.13	86.9	123.1	109.74	92.56	99.59	99.17	114.89	116.37	69.85	TCI
NET	2.4	−2.69	−11.87	−13.1	23.1	9.74	−7.44	−0.41	−0.83	14.89	16.37	−30.15	54.78
NPDC	6	5	4	3	11	10	2	5	3	8	9	0	
Panel B: COVID-19													
LINK	22.64	17.72	17.84	0.15	2.9	1.91	1.01	1.61	1.01	15.42	15.49	2.29	77.36
BAT	16.8	20.97	16.74	0.15	4.88	2.94	0.98	1.53	0.88	15.89	15.75	2.49	79.03
MKR	17.7	17.46	20	0.12	4.21	2.51	0.91	0.9	1.34	16.26	16.38	2.2	80
Livestock	4.84	7.43	6.93	37.92	8.3	3.68	1.87	1.32	3.85	11.36	10.42	2.07	62.08
Commodity	0.69	0.94	0.87	2.26	42.35	37.32	0.68	0.41	0.69	5.93	5.31	2.54	57.65
Energy	0.46	0.56	0.58	2.22	42.63	44.69	0.6	0.37	0.6	3.06	2.82	1.42	55.31
Precious. Metal	6.45	5.45	4.62	0.45	1.07	0.74	46.81	1.99	1.18	10.85	13.01	7.38	53.19
Industrial. Metals	3.01	2.82	3.17	4.85	10.75	5.23	5.24	47.4	5.61	5.78	4.63	1.5	52.6
Agriculture	6.05	5.76	5.31	1.92	6.35	3.99	2.79	2.51	44.31	9.06	8.19	3.75	55.69
ACWI	12.85	13.69	13.22	0.2	5.15	2.85	1.38	1.06	0.99	22.53	21.86	4.21	77.47
WORLD	12.33	13.29	12.78	0.22	5.69	3.25	1.66	1.31	0.92	21.77	22.4	4.38	77.6
EM	1.65	2.35	2.12	2.26	12.62	8.58	5.14	2.54	2.08	6.42	5.49	48.75	51.25
TO	82.83	87.47	84.19	14.81	104.56	73	22.27	15.55	19.17	121.8	119.35	34.23	779.22
Inc.Own	105.47	108.44	104.19	52.73	146.91	117.68	69.08	62.96	63.48	144.34	141.75	82.97	TCI
NET	5.47	8.44	4.19	−47.27	46.91	17.68	−30.92	−37.04	−36.52	44.34	41.75	−17.03	64.93
NPDC	4	6	5	2	10	9	3	1	2	10	9	5	
Panel C: Russian-Ukraine War													
LINK	27.51	19.18	14.45	4.49	1.09	1.19	2.43	2.48	1.21	12.35	12.63	0.99	72.49
BAT	24.69	31.17	12.2	2.9	0.56	0.66	1.14	3.4	0.98	10.45	11.29	0.57	68.83
MKR	19.91	15.22	27.09	3.45	0.59	0.67	2.1	2.34	0.64	13.3	13.27	1.41	72.91
Livestock	2.72	2.31	5.34	60.59	1.09	1.06	2.31	4.79	1.85	6.95	6.45	4.54	39.41
Commodity	1.88	2.35	1.97	4.2	26.44	25.05	12.06	4.75	12.71	3.25	3.09	2.26	73.56
Energy	2.02	2.3	2.29	4.05	26.69	26.77	13.9	4.05	9.84	2.86	2.59	2.65	73.23
Precious. Metal	4.54	3.07	7.07	4.79	4.64	4.85	47.98	4.04	3.18	6.22	4.94	4.67	52.02
Industrial. Metals	1.5	1.49	1.27	10.94	6.01	3.86	6.84	43.83	6.59	8.06	7.35	2.28	56.17
Agriculture	2.39	4.8	2.24	2.88	8.85	5.75	2.42	2.14	64.21	1.76	2.12	0.44	35.79
ACWI	10.73	7.12	8.54	1.99	0.84	0.72	2.42	3.12	0.36	31.66	29.58	2.92	68.34
WORLD	11.05	7.41	8.23	1.82	1.03	0.85	2.07	2.67	0.34	30.56	32.53	1.44	67.47
EM	2.65	4.02	3.76	21.67	3.82	3.38	3.54	6.88	1.07	10.89	8.38	29.94	70.06
TO	84.09	69.27	67.34	63.18	55.21	48.03	51.21	40.66	38.77	106.64	101.69	24.18	750.27
Inc.Own	111.6	100.44	94.43	123.76	81.65	74.8	99.2	84.49	102.98	138.3	134.22	54.13	TCI
NET	11.6	0.44	−5.57	23.76	−18.35	−25.2	−0.8	−15.51	2.98	38.3	34.22	−45.87	62.52
NPDC	7	6	6	8	3	1	3	5	5	11	10	1	

Note: This table presents the estimations of the static returns connectedness between Defi, commodities and Islamic stock markets for COVID-19 (Jan, 20 to Dec, 20), Russia-Ukraine war (Jan, 22 to Dec, 22) and full sample (Dec, 19 to Mar 2023).

recipients of spillovers with significant levels. Therefore, during COVID-19, shocks to one market are more likely to be transmitted to other markets in the selected DeFi assets, commodities, and Islamic stocks. Similarly, in Fig. 2b (RU-war), the total return (green line) and volatilities (red line) are connected to all selected stock markets. The return index of all the selected stock indices shows fluctuations at first and then decreases, while volatility is reduced because of the significant RU-war risk effect. Due to the RU-war's greater risk spillover effect, the volatility index shows consistent receivers of all DeFi assets, commodities, and Islamic stock indices and is similar to (Younis et al., 2024).

Furthermore, Figs. 3a and 3b separately show each index's overall net return and net volatility series connectedness graphs and their fluctuations due to COVID-19 and the RU-war. The net return connectedness index of DeFi assets, commodities, and Islamic stock indices

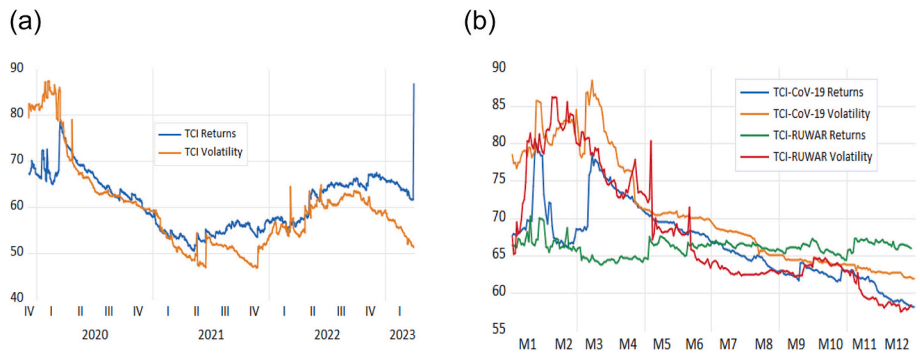

Fig. 2. a, b Total returns and volatility connectedness of Defi, commodities and Islamic stock markets for COVID-19 (January, 20 to December, 20), Russia-Ukraine war (c = January, 22 to Oct, 22) and full sample (Dec, 19 to Mar 2023).

shows a smooth line touching zero and small changes during both crisis episodes. Meanwhile, the net volatility connectedness index of DeFi assets, commodities, and Islamic stock indices show higher fluctuations during COVID-19 and the RU-war. This could be because these assets are more closely linked to risky assets, such as DeFi assets, during crises and have less liquidity than stock markets. Thus, these stock indices are susceptible to spillover effects in various markets.

Finally, we created a network graph of DeFi assets, commodities, and Islamic stock markets to test the connectivity, as shown in Fig. (4a, 4b). The network graph shows the connections between DeFi assets, commodities, and Islamic equities in COVID-19 and the Russian War in Figs. a and 4b. Node size measures how connected a particular series is to the system as a whole. The node color indicates whether the series is a net shock transmitter (blue) or a receiver (yellow). The nodes in blue and yellow represent the series that have a propensity to shock to other series and transmit shocks to them. These metrics display a series of degrees of correlation with other series and the direction of the correlation (i.e., whether the series has a propensity to transmit shocks).

According to the return network connectedness findings in Fig. a (COVID-19), ACWI, world, and commodity, followed by BAT and energy, are the most significant shock transmitters. The principal shock receivers are livestock, precious metals, industrial metals, and the agricultural stock market. Similarly, according to the volatility network connectedness findings in Fig. 4b (COVID-19), ACWI, world, and commodity, followed by LINK, BAT, MKR, and energy as shock transmitters. The principal shock receivers are livestock, precious metals, industrial metals, and the agricultural stock market. Further market the return network connectedness indicators in Fig. 4b (RU-war). The main shock transmitters are ACWI, World, and commodity, followed by BAT, LINK, MKR, and energy stocks. The shock receivers are EM, agriculture, and precious and industrial metals. In the market, the volatility network connectedness indicators in Fig. 4b (RU-war), the main shock transmitters are ACWI, World, livestock, BAT, LINK, and agriculture stocks. The shock receivers are EM, industrial metals, energy, and commodities. These findings are consistent with those in the connectedness tables.

4.4. Within and between connectedness among return-volatility connectedness

Table 5 elucidates the interconnectedness in return spillover among DeFi assets, commodities, and Islamic stock indices, segmented into three temporal phases: overall, COVID-19, and the RU-war periods. Throughout the aggregate period (Part A), DeFi assets manifest high intragroup connectedness, moderate interconnectivity with Islamic markets, and minimal association with commodities. Optimal portfolio diversification from DeFi assets implies investment in Islamic markets, whereas commodities are secure havens. In the COVID-19 period (Part B), Defi and commodities maintained previous connectedness, whereas Islamic stocks exhibited moderate links with commodities and low connectivity with DeFi assets. This suggests potential portfolio diversification opportunities for investors in Islamic assets through commodities, with DeFi assets serving as safe havens. During the RU-war period (Part C), DeFi assets maintained consistent connectedness, while commodities demonstrated moderate internal interconnectivity with Islamic markets, yet a limited association with DeFi assets. Islamic stock echo patterns observed during the COVID-19 pandemic Consequently, DeFi assets offer stability, commodities provide diversification potential, and Islamic markets present a balanced option for strategic portfolio management across distinct geopolitical and economic scenarios.

Table 6 presents a comprehensive summary of volatility connectedness among DeFi assets, commodities, and Islamic stock indices across three distinct periods: Overall, COVID-19, and RU-war. Overall, DeFi assets exhibit substantial interconnectedness within their realm, with moderate links to Islamic markets and minimal connections to commodities. Optimal portfolio diversification suggests investment in Islamic markets, whereas commodities serve as secure havens. In the COVID-19 period, patterns persisted, with Islamic stocks showing moderate links to commodities. DeFi assets maintained consistent connections during the RU-war period, whereas commodities displayed moderate internal and Islamic links. This analysis informs strategic portfolio management by highlighting DeFi assets' stability, commodities' diversification potential, and balanced options in Islamic markets. Hence, the outcomes of this study are consistent with those of previous studies on cross-market analysis of different crises (Chowdhury et al., 2023; Hasan et al., 2022; Younis et al., 2024; Yousaf et al., 2023).

However, the demand for digital art and collectibles surged during the COVID-19 pandemic, leading to a considerable increase in the market value of DeFi assets. Meanwhile, the worldwide economic recession has also increased the interest in DeFi tokens and stablecoins for investment and financial services. As a result, the DeFi market slowed, and return volatility in the larger financial markets increased. The rapid gains in DeFi assets have caused investors' perceptions to shift, connecting DeFi to other stock markets and commodities. The interplay between DeFi assets, commodities, and Islamic equities in distinct crisis phases is molded by diverse market characteristics and investor conduct, which can substantially impact their interdependence and the overall dynamics of the market. Investor perceptions of DeFi assets frequently change significantly during stressful market times. First, investors may view DeFi assets as high-risk, which could cause capital to leave the market in favor of safer and more conventional assets. During the COVID-19 epidemic, investors seeking decentralized alternatives amid fears about central bank policy, and inflation led to the recovery of DeFi assets after the first sell-off. The relationship between DeFi and conventional markets may change as a result of this altered mood, which may occasionally result in decoupling during periods of acute stress or an increased correlation when markets settle.

Furthermore, energy and precious metals, in particular, are commodities that frequently act as safe havens during times of crisis,

Fig. 3. Net Returns and volatility directional connectedness of Defi, commodities and Islamic stock markets for COVID-19 (January, 20 to December, 20), Russia-Ukraine war (c = January, 22 to Oct, 22) and full sample (Dec, 19 to Mar 2023).

increasing the cost of these physical assets. For example, during geopolitical conflicts or inflationary periods, such as the RU-war or the inflation surge of 2022, the price of commodities usually rises because supply chains become disrupted and the demand for secure assets such as gold increases. These market dynamics may establish inverse associations with stocks and other riskier assets, which would help in portfolio diversification. However, the degree of correlation between commodities and the other asset classes varies. For instance, if a crisis affects global economic growth, energy commodities may become more associated with equities, resulting in simultaneous drops in both sectors.

Furthermore, Shariah-compliant Islamic stocks, which prioritize moral and socially conscious investing, may cause distinct behavioral patterns in times of crises. As they typically steer clear speculative assets and high levels of debt, these stocks may be more resilient to market downturns. Because Islamic stocks perform more steadily than conventional equities during crises, they may draw risk-averse investors looking for lower-volatility ethical investment options. For instance, Islamic financial markets were less affected by the global financial crisis because they forbade high-risk financial operations. This created the impression that Islamic stocks are reliable moral substitutes. This may affect how linked they are to international markets, which could be advantageous for diversification in times of extreme volatility. However, investor

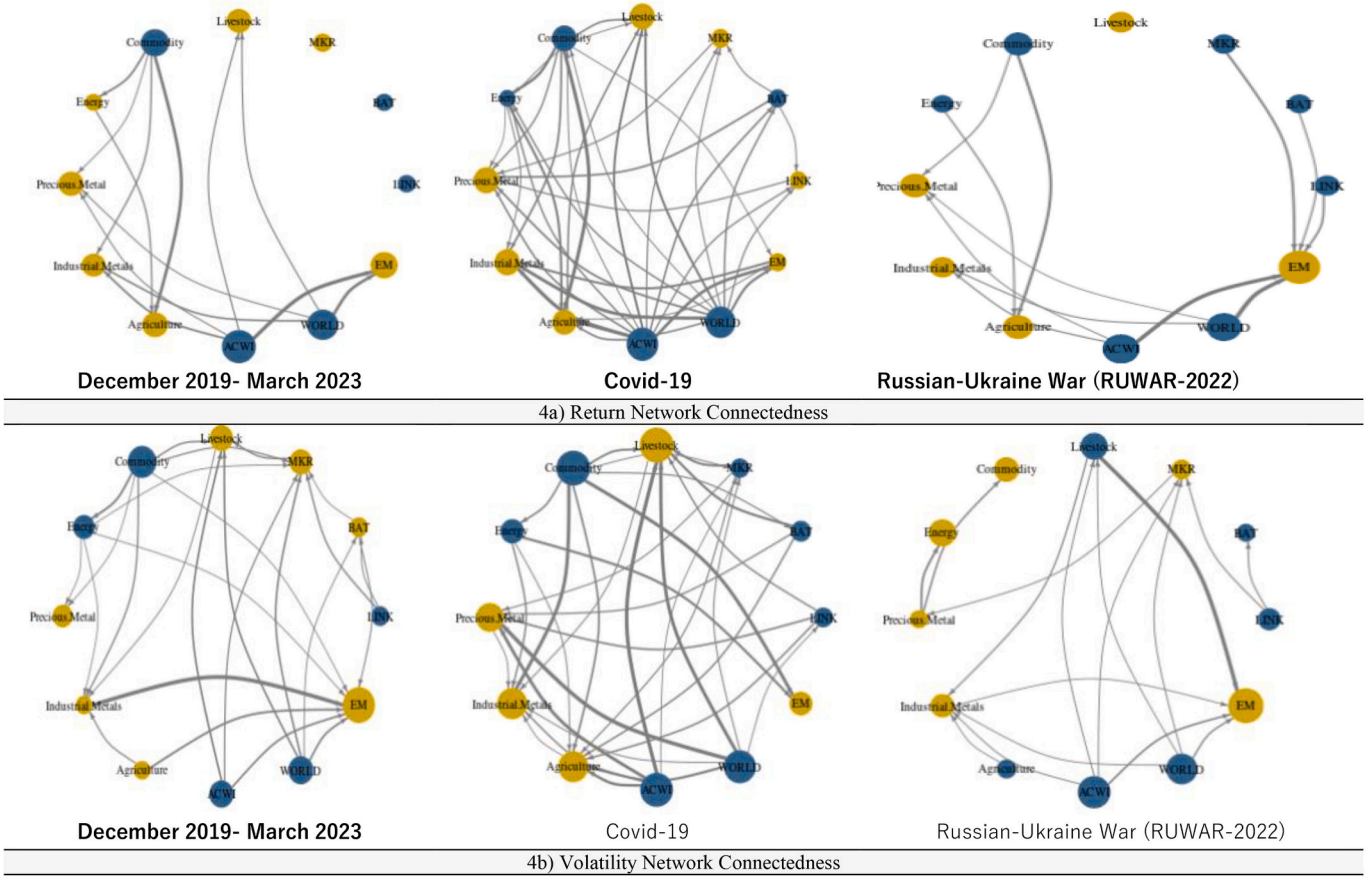

Fig. 4. a, bNetwork returns and volatility connectedness of Defi, commodities and Islamic stock markets for COVID-19 (January, 20 to December, 20), Russia-Ukraine war (Jan, 22 to Oct, 22) and full sample (Dec, 19 to Mar 2023).

behavior shifts in response to market conditions affect how various asset groups interact during crises. Comprehending these processes can yield significant insights for managing portfolios and devising risk-mitigation strategies in crises.

5. Concluding remarks

Understanding the distinctive features and dynamics of each investment category is necessary to analyze the risks and returns of DeFi assets, commodities, and Islamic stock markets. DeFi assets represent a new type of cryptocurrency investment. These digital assets use smart contracts on blockchain networks to offer financial services such as borrowing, lending, trading, and yield farming. Energy, metals, agricultural products, and gold are commodities. They are sold in multiple commodity marketplaces and serve as crucial resources. The supply and demand dynamics, which can be affected by geopolitical events, climatic circumstances, and economic trends, significantly affect commodity pricing. Islamic stock markets follow the Shariah guidelines, which prohibit some financial activities, including prohibition of riba (interest), sharing risks, prohibition of gharar (uncertainty), and prohibition of maysir (gambling).

This study uses a TVP-VAR methodology to investigate the risk-return spillover and network connectivity of DeFi assets, commodities, and the Islamic market during the COVID-19 and RU-war. The mean return on a few commodities, DeFi assets, and Islamic indices, excluding livestock, was positive. All indices indicate positive mean returns except for livestock, energy, and commodities. Conversely, the highest means of return are for the energy index, followed by commodity indices. By contrast, the highest negative values for DeFi assets and the Islamic EM index had the highest mean variance for fire assets. The commodity index is a net greater and significantly significant transmitter, and the EM index receives risk spillover in the system during the entire RU-war sample according to risk-spillover connectivity. The return spillover connectedness suggests that the system's transmitters and EM index receivers run the risk of spillover during the RU-war and the full sample. The ACWI is a net greater and significantly significant index. Additional livestock indexes are the net greater and more substantial risk-return spillover receivers of COVID-19. Finally, commodities, WDI, ACWI, and EM accounted for a greater proportion of the variation during these crisis events (75 %).

This study might impact how financial institutions and decision makers create crisis management strategies. DeFi protocols are based on smart contracts with flaws that can be exploited or hacked to cause economic loss. DeFi operates in some legal limitations in many places, and any regulatory actions could affect how well and how much DeFi's assets are worth. Extreme price volatility, which can result in substantial profits or losses in a short period, is characteristic of cryptocurrency markets, particularly DeFi assets. It could be difficult to enter or exit positions without affecting the market prices of some DeFi assets because of their limited liquidity. According to the protocol, lending or borrowing assets can include counterparty risks. The innovative nature of the initiatives and enormous demand for decentralized financial services make investments in DeFi highly profitable. Yield farming involves receiving rewards by providing liquidity to the DeFi protocol. This carries greater risks, but has the potential to produce significant benefits. Our study showed similar results to Ali et al. (2023); (Yousaf et al., 2023) and Husain, Karim, and Sensoy (2024).

Even with their volatility, DeFi assets can offer opportunities for large profits and act as a buffer against the risks associated with the traditional financial system. Because they are recognized as safe havens

Table 5
Summary of Return Statistics Connectedness.

Indicators	Recipient	Transmitter	High Connectedness	Moderate Connectedness	Low Connectedness	Indicators/ Countries pairs	Safe Haven	Diversification
Panel A: Overall Sample								
DeFi		LINK	LINK, BAT, MKR	ACWI, WORLD, EM	Livestock, Energy, Precious Metals, Industrial Metals, and Agriculture	DeFi assets	Commodity Market	Islamic Markets
		BAT	LINK, BAT, MKR	ACWI, WORLD, EM	Livestock, Energy, Precious Metals, Industrial Metals and Agriculture	DeFi assets	Commodity Market	Islamic Markets
	MKR		LINK, BAT, MKR	ACWI, WORLD, EM	Livestock, Energy, Precious Metals, Industrial Metals, and Agriculture	DeFi assets	Commodity Market	Islamic Markets
Commodity	Livestock		Livestock	ACWI, WORLD	BAT, LINK, MKR, Commodity, Energy, Precious Metals, Industrial Metals, Agriculture and EM	Commodity Market	DeFi assets and other commodities	Islamic Markets
		Commodity	Commodity and Energy	Industrial Metals, Agriculture, ACWI and WORLD	LINK, BAT, MKR, Livestock, Precious Metals and EM	Commodity Market	DeFi assets and other commodities	Islamic Markets
	Energy		Commodity and Energy	Agriculture, ACWI, and WORLD	Industrial Metals, LINK, BAT, MKR, Livestock, Precious Metals and EM	Commodity Market	DeFi assets and other commodities	Islamic Markets
	Precious Metals		Precious Metals	Commodities, Industrial Metals, ACWI and WORLD	LINK, BAT, MKR, Livestock, Energy, Precious Metal, Agricultures and EM	Commodity Market	DeFi assets and other commodities	Islamic Markets
	Industrial Metals		Commodity, Industrial Metals	Energy, ACWI, WORLD, EM	LINK, BAT, MKR, Livestock, Precious Metal, and Agricultures	Commodity Market	DeFi assets and other commodities	Islamic Markets
	Agriculture		Agriculture and Commodity	Industrial Metals and Energy	LINK, BAT, MKR, Livestock, Precious Metal, ACWI, WORLD and EM	Commodity Market	Defi Assets and Islamic Markets	Commodity Market
Islamic Stock Market		ACWI	ACWI, WORLD, and EM	LINK, BAT, MKR, Commodity, Energy, Industrial Metals	Livestock, Precious Metals and Agriculture	Islamic Markets	Some Commodities	Defi assets and Some Commodities
		WORLD	ACWI, WORLD	LINK, BAT, MKR, Commodity, Energy, Industrial Metals and EM	Livestock, Precious Metals and Agriculture	Islamic Markets	Some Commodities	Defi assets and Some Commodities
	EM		ACWI, WORLD EM	Industrial Metals	LINK, BAT, MKR, Livestock, Commodity, Energy, Precious Metals and Agriculture	Islamic Markets	Defi assets and all Commodities	
Panel B: COVID-19								
DeFi	LINK		LINK, BAT, MKR	ACWI, and WORLD	EM, Livestock, Energy, Precious Metal, Industrial Metals and Agriculture	Defi assets	Commodity Market	Islamic Markets
		BAT	LINK, BAT, MKR	ACWI, and WORLD	EM, Livestock, Energy, Precious Metal, Industrial Metals and Agriculture	Defi assets	Commodity Market	Islamic Markets
	MKR		LINK, BAT, MKR	ACWI, and WORLD	EM, Livestock, Energy, Precious Metal, Industrial Metals and Agriculture	Defi assets	Commodity Market	Islamic Markets
Commodities	Livestock		Livestock	Commodity, ACWI, WORLD	BAT, LINK, MKR, Energy, Precious Metals, Industrial Metals, Agriculture and EM	Commodity Market	DeFi assets and other commodities	Islamic Markets
		Commodity	Commodity and Energy	Industrial Metals, Agriculture, ACWI and WORLD	LINK, BAT, MKR, Livestock, Precious Metals and EM	Commodity Market	DeFi assets and other commodities	Islamic Markets
		Energy	Commodity and Energy	Industrial Metals, Agriculture, ACWI, WORLD, and EM	LINK, BAT, MKR, Livestock, Precious Metals	Commodity Market	DeFi assets and other commodities	Islamic Markets

(*continued on next page*)

Table 5 (*continued*)

Indicators	Recipient	Transmitter	High Connectedness	Moderate Connectedness	Low Connectedness	Indicators/ Countries pairs	Safe Haven	Diversification
	Precious Metals		Precious Metals	BAT, ACWI, and WORLD	LINK, MKR, Livestock, Energy, Precious Metal, Commodities, Industrial Metals, Agricultures and EM	Commodity Market	DeFi assets and other commodities	Islamic Markets
	Industrial Metals		Industrial Metals	Commodity, Energy, ACWI, WORLD, EM	LINK, BAT, MKR, Livestock, Precious Metal, and Agricultures	Commodity Market	DeFi assets and other commodities	Islamic Markets
	Agriculture		Agriculture and Commodity	Livestock, Industrial Metals, Energy, ACWI, WORLD and EM	LINK, BAT, MKR, Precious Metal,	Commodity Market	Defi Assets	Commodity Market and Islamic Markets
Islamic Stock Market		ACWI	ACWI, WORLD, and EM	Commodity, Energy, Industrial Metals	LINK, BAT, MKR, Livestock, Precious Metals and Agriculture	Islamic Markets	Defi assets and Some Commodities	Defi assets and Some Commodities
		WORLD	ACWI, WORLD, and EM	Commodity, Energy, Industrial Metals	LINK, BAT, MKR, Livestock, Precious Metals and Agriculture	Islamic Markets	Defi assets and Some Commodities	Defi assets and Some Commodities
	EM		ACWI, WORLD EM	Commodity, Energy, Industrial Metals and Agriculture	LINK, BAT, MKR, Livestock, Precious Metals	Islamic Markets	Defi assets	Commodity Market
Panel C: Russian-Ukraine War								
DeFi		LINK	LINK, BAT, MKR	ACWI AND WORLD	Livestock, Commodity, Energy, Precious Metals, Industrial Metals, Agriculture	Defi assets	Commodity Market	Islamic Stock Market
		BAT	LINK, BAT, MKR	ACWI AND WORLD	Livestock, Commodity, Energy, Precious Metals, Industrial Metals, Agriculture	Defi assets	Commodity Market	Islamic Stock Market
		MKR	LINK, BAT, MKR	ACWI AND WORLD	Livestock, Commodity, Energy, Precious Metals, Industrial Metals, Agriculture	Defi assets	Commodity Market	Islamic Stock Market
Commodities	Livestock		Livestock		BAT, LINK, MKR, Energy, Precious Metals, Industrial Metals, Agriculture, Commodity, ACWI, WORLD and EM	Commodity Market		DeFi assets, Islamic Markets and other commodities
		Commodity	Commodity Energy and agriculture	Precious Metals, and Industrial Metals,	LINK, BAT, MKR, Livestock, ACWI, WORLD and EM	Commodity Market	DeFi assets and Islamic Market	Commodities like precious and industrial metals
		Energy	Commodity and Energy	Precious Metals, Industrial Metals, and Agriculture	LINK, BAT, MKR, Livestock, ACWI, WORLD, and EM	Commodity Market	DeFi assets and Islamic Market	Commodities like precious and industrial metals
	Precious Metals		Commodities, and Precious Metals	Energy, Industrial Metals, Agriculture, ACWI and WORLD	BAT, LINK, MKR, Livestock, Precious Metal, and EM	Commodity Market	DeFi assets	Islamic Markets
	Industrial Metals		Commodity, and Industrial Metals	Energy, Precious Metal, Agricultures, and ACWI, WORLD, EM	LINK, BAT, MKR, Livestock	Commodity Market	DeFi assets	Islamic Markets and Precious Metals
	Agriculture		Agriculture, Energy and Commodity	Industrial Metals, and Precious Metal,	LINK, BAT, MKR, Livestock, ACWI, WORLD and EM	Commodity Market	Defi Assets and Islamic Market	Commodities like precious metals
Islamic Stock Market		ACWI	ACWI, WORLD	LINK, BAT, MKR and EM	Commodity, Energy, Industrial Metals, Livestock, Precious Metals and Agriculture	Islamic Markets	Commodity Market	Defi assets
		WORLD	ACWI, WORLD	LINK, BAT, MKR and EM	Commodity, Energy, Industrial Metals, Livestock, Precious Metals and Agriculture	Islamic Markets	Commodity Market	Defi assets
	EM		ACWI, WORLD EM	LINK, BAT, MKR Industrial Metals	Commodity, Energy, Livestock, Precious Metals and Agriculture	Islamic Markets	Defi assets	Commodity Market

Note: This table presents the summary of the static returns connectedness between Defi, commodities and Islamic stock markets for COVID-19 (Jan, 20 to Dec, 20), Russia-Ukraine war (Jan, 22 to Dec, 22) and full sample (Dec, 19 to Mar 2023).

Table 6
Summary of Volatility Statistics Connectedness.

Indicators	Recipient	Transmitter	High Connectedness	Moderate Connectedness	Low Connectedness	Indicators/ Countries pairs	Safe Haven	Diversification
Panel A: Overall Sample								
DeFi		LINK	LINK, BAT, MKR	ACWI, WORLD	Livestock, Energy, Precious Metals, Industrial Metals, Agriculture, and EM	DeFi assets	Commodity Market	Islamic Markets
	BAT		LINK, BAT, MKR	ACWI, WORLD	Livestock, Energy, Precious Metals, Industrial Metals, Agriculture, and EM	DeFi assets	Commodity Market	Islamic Markets
	MKR		LINK, BAT, MKR	ACWI, WORLD	Livestock, Energy, Precious Metals, Industrial Metals, Agriculture, and EM	DeFi assets	Commodity Market	Islamic Markets
Commodity	Livestock		Livestock	ACWI, WORLD, commodity and agriculture	BAT, LINK, MKR, Energy, Precious Metals, Industrial Metals, and EM	Commodity Market	DeFi assets and other commodities	Islamic Markets
		Commodity	Commodity and Energy		Industrial Metals, Agriculture, ACWI, WORLD LINK, BAT, MKR, Livestock, Precious Metals and EM	Commodity Market	DeFi assets, Islamic market and other commodities	
		Energy	Commodity and Energy		Industrial Metals, Agriculture, ACWI, WORLD LINK, BAT, MKR, Livestock, Precious Metals and EM	Commodity Market	DeFi assets, Islamic market and other commodities	
	Precious Metals		Precious Metals	Industrial Metals, and Livestock	LINK, BAT, MKR, Commodities, Energy, Precious Metal, Agricultures, ACWI WORLD and EM	Commodity Market	DeFi assets, Islamic Markets and other commodities	
	Industrial Metals		Industrial Metals	Livestock, commodity, precious metal and agriculture	LINK, BAT, MKR,, Energy, ACWI, WORLD, EM	Commodity Market	DeFi assets, Islamic Markets	other commodities
	Agriculture		Agriculture and Commodity	Livestock, commodity, precious metal and agriculture	LINK, BAT, MKR, Energy, ACWI, WORLD, EM	Commodity Market	DeFi assets, Islamic Markets	other commodities
Islamic Stock Market		ACWI	LINK, BAT, MRK, ACWI, WORLD	EM	Livestock, Precious Metals, Commodity, Energy, Industrial Metals and Agriculture	Islamic Markets and Defi assets	Commodities	EM
		WORLD	LINK, BAT, MRK, ACWI, WORLD		Livestock, Precious Metals, Commodity, Energy, Industrial Metals and Agriculture and EM	Islamic Markets and Defi assets	Commodities and EM	
	EM		ACWI, WORLD EM	Industrial Metals	LINK, BAT, MKR, Livestock, Commodity, Energy, Precious Metals and Agriculture	Islamic Markets	Defi assets and all Commodities	
Panel B: COVID-19								
DeFi		LINK	LINK, BAT, MKR, ACWI, and WORLD		Livestock, Energy, Precious Metal, Industrial Metals, Agriculture and EM	Defi assets and Islamic Markets	Commodity Market	
		BAT	LINK, BAT, MKR, ACWI, and WORLD	Energy	Livestock, Precious Metal, Industrial Metals, Agriculture and EM	Defi assets and Islamic Markets	Commodity Market	
		MKR	LINK, BAT, MKR, ACWI, and WORLD	Energy	Livestock, Precious Metal, Industrial Metals, Agriculture and EM	Defi assets and Islamic Markets	Commodity Market	
Commodities	Livestock		Livestock, ACWI, WORLD	BAT, LINK, MKR, Commodity	Energy, Precious Metals, Industrial	Commodity Market,	other commodities	DeFi assets

(*continued on next page*)

Table 6 (*continued*)

Indicators	Recipient	Transmitter	High Connectedness	Moderate Connectedness	Low Connectedness	Indicators/ Countries pairs	Safe Haven	Diversification
					Metals, Agriculture and EM	Islamic Markets		
		Commodity	Commodity and Energy	Industrial Metals, Agriculture, ACWI and WORLD	LINK, BAT, MKR, Livestock, Precious Metals and EM	Commodity Market	DeFi assets and other commodities	Islamic Markets
		Energy	Commodity and Energy	Industrial Metals, Agriculture, ACWI, WORLD, and EM	LINK, BAT, MKR, Livestock, Precious Metals	Commodity Market	DeFi assets and other commodities	Islamic Markets
	Precious Metals		Precious Metals, ACWI, and WORLD	BAT, LINK, MKR	Livestock, Energy, Precious Metal, Commodities, Industrial Metals, Agricultures and EM	Commodity Market, and Islamic Market	other commodities	DeFi assets
	Industrial Metals		Industrial Metals and Commodity	Livestock,Energy, precious metal, agriculture, ACWI, WORLD	LINK, BAT, MKR, and EM	Commodity Market	DeFi assets and EM	Islamic Markets and some commodities
	Agriculture		Agriculture	LINK, BAT, MKR, commodity,ACWI, WORLD and EM	Livestock, Industrial Metals, Energy, Precious Metal,	Commodity	Other commodity	Defi assets and Islamic Markets
Islamic Stock Market		ACWI	LINK, BAT, MKR, ACWI, WORLD,	Commodity and EM	Livestock,, Energy, Industrial Metals, Precious Metals and Agriculture	Islamic Markets and Defi assets	Some Commodities and EM	Other Commodities
		WORLD	LINK, BAT, MKR, ACWI, WORLD,	Commodity and EM	Livestock,, Energy, Industrial Metals, Precious Metals and Agriculture	Islamic Markets and Defi assets	Some Commodities and EM	Other Commodities
	EM		Commodity and EM	Energy, Precious metals, ACWI, WORLD	LINK, BAT, MKR, Livestock, Commodity, Industrial Metals and Agriculture,	Commodity	Defi assets and commodities	Islamic Market
Panel C: Russian-Ukraine War								
DeFi		LINK	LINK, BAT, MKR, ACWI AND WORLD	Livestock	Commodity, Energy, Precious Metals, Industrial Metals, Agriculture	Defi assets and Islamic Market	Commodity Market	Livestock
		BAT	LINK, BAT, MKR, ACWI AND WORLD		Livestock,Commodity, Energy, Precious Metals, Industrial Metals, Agriculture	Defi assets and Islamic Market	Commodity Market	
	MKR		LINK, BAT, MKR, ACWI AND WORLD		Livestock,Commodity, Energy, Precious Metals, Industrial Metals, Agriculture	Defi assets and Islamic Market	Commodity Market	
Commodities		Livestock	Livestock		BAT, LINK, MKR, Energy, Precious Metals, Industrial Metals, Agriculture, Commodity, ACWI, WORLD and EM	Commodity Market		DeFi assets, Islamic Markets and other commodities
	Commodity		Energy, Commodity precious metal, and agriculture	Livestock and industrial metal	LINK, BAT, MRK, ACWI, WORLD and EM	Commodity Market	DeFi assets and Islamic Market	Commodities like Livestock and industrial metals
	Energy		Energy, Commodity precious metal, and agriculture	Livestock and industrial metal	LINK, BAT, MRK, ACWI, WORLD and EM	Commodity Market	DeFi assets and Islamic Market	Commodities like Livestock and industrial metals
	Precious Metals		Precious Metals	BAT	BAT, LINK, MKR, Livestock, Precious Metal, Energy, Industrial Metals, Agriculture, ACWI WORLD and EM	Commodity Market	DeFi assets, other commodities and Islamic market	Defi asset like BAT
	Industrial Metals		Livestock and Industrial Metals	Commodity, Precious Metal, Agricultures, ACWI, and WORLD	LINK, BAT, MKR, energy and EM	Commodity Market	DeFi assets	Islamic Markets and Precious Metals

(*continued on next page*)

Table 6 (*continued*)

Indicators	Recipient	Transmitter	High Connectedness	Moderate Connectedness	Low Connectedness	Indicators/ Countries pairs	Safe Haven	Diversification
		Agriculture	Agriculture	Commodity and BAT	LINK, MKR, Livestock, Energy, Precious metals, industrial metals, ACWI, WORLD and EM	Commodity Market	Defi Assets, commodities and Islamic Market	Commodities and Defi assets like BAT
Islamic Stock Market		ACWI	LINK,ACWI, WORLD	BAT, MKR	Commodity, Energy, Industrial Metals, Livestock, Precious Metals Agriculture and EM	Islamic Markets	Commodity Market	Defi assets
		WORLD	LINK,ACWI, WORLD	BAT, MKR	Commodity, Energy, Industrial Metals, Livestock, Precious Metals Agriculture and EM	Islamic Markets	Commodity Market	Defi assets
	EM		Livestock, ACWI, EM	BAT,WORLD and Industrial Metals	LINK, Commodity, Energy, Precious Metals and Agriculture	Islamic Markets	Defi assets	Commodity Market

Note: This table presents the summary of the static volatility connectedness between Defi, commodities and Islamic stock markets for COVID-19 (Jan, 20 to Dec, 20), Russia-Ukraine war (Jan, 22 to Dec, 22) and full sample (Dec, 19 to Mar 2023).

in times of crisis, commodities, especially those that include energy and precious metals, can improve portfolio diversification and lower the overall risk. In contrast to their focus on moral and socially conscious investment, Islamic stocks provide stability and reduced volatility, making them an excellent complement to portfolios striving for long-term robustness. By striking a balance between these asset classes, investors can increase returns while reducing risks and take advantage of each asset class's distinct advantages in various market scenarios.

Due to the vulnerability of their markets to external influences, commodities can experience huge price changes. The storage expenses for physical goods can impact total profits. Government regulations and policies can affect commodity production, distribution, and trade. Owing to their frequent poor correlation with conventional financial assets, commodities may help portfolio diversification. Given that their values might increase during economic instability, some commodities such as gold are frequently regarded as hedges against inflation. Based on its decentralized structure, transparency, and liquidity processes, this study demonstrates that DeFi assets offer stability and diversity in the Islamic market. The Islamic market's risk-sharing policies and ban on excessive investment serve as diversifiers during times of turmoil. Future research must focus on risk reduction, regulatory ramifications, and cooperation to fortify DeFi networks and ensure the robustness of Islamic markets. Investors should employ stable coins, monitor market conditions, and include DeFi assets in their portfolios.

Islamic stock markets require enterprises to abide by Shariah laws, which might limit investments in particular sectors including the alcoholic beverage, gambling, and pork industries. Islamic stock markets are susceptible to changes in the overall economy, similar to the traditional stock markets. Islamic finance encourages moral investing that adheres to the Shariah standards, which may attract investors to seek investments that reflect their values. Long-term investment techniques that may increase portfolio stability are frequently used. Understanding the risk-return trade-offs is essential for each scenario. It is critical to conduct an analysis before making an investment selection in any of these categories because different individuals have different risk tolerances and financial goals. Further stock options can be added to deepen our understanding of the integration of economic and ecosystem structures, and their outer performance functions.

Regulators should adopt a balanced policy approach to regulate decentralized financial assets, including security standards, incident reporting systems, insurance mandates, international cooperation, and regulatory sandboxes. They should promote financial inclusion and stability during crises, and integrate DeFi into existing financial systems through hybrid financial products and compliance technology. Strict security requirements and frequent audits are necessary to reduce DeFi technology vulnerabilities, including cyber threats and smart contract exploitation. DeFi can be easily incorporated into a larger financial system without hindering innovation. Regulators can lower systemic risks during crises by improving portfolio resilience and diversification by integrating DeFi assets into the current financial systems. In addition to maximizing the advantages of decentralized finance, this strategy ensures that the financial ecosystem is safe and stable, even in the face of new threats.

In conclusion, this research offers a thorough examination of the relationships among DeFi assets, commodities, and Islamic stocks, especially in times of market strain. These varied asset classes interact, as demonstrated by the findings, which also provide information on how they may be used to improve portfolio stability and resilience. Financial managers and policymakers can create a more robust global financial ecosystem by carefully combining DeFi assets for innovation and risk mitigation, commodities for diversification, and Islamic stocks for stability in their crisis management plans. Studies on the connection between DeFi assets, commodity markets, and Islamic market returns and volatility during the COVID-19 pandemic and the RU-war have been limited to significant Defi, financial assets, and Islamic markets. Future research should use firm-level time-series data, particularly wavelet coherence, and consider right-tail risks and sectoral Islamic markets for comparison. Further, our sample is limited to COVID-19 and the RU-war and can be extended to the oil crisis and the Israel-Humas war. Future research should compare the Islamic market's performance during crises with that in other international stock markets, NFTs, and cryptocurrencies.

Data availability

Data will be made available on request.

References

Ahmed, W. M. (2019). Islamic and conventional equity markets: Two sides of the same coin, or not? *The Quarterly Review of Economics and Finance, 72*, 191–205.

Akhtar, S., & Jahromi, M. (2017). Impact of the global financial crisis on Islamic and conventional stocks and bonds. *Accounting and Finance, 57*(3), 623–655.

Ali, S., Ijaz, M. S., & Yousaf, I. (2023). Dynamic spillovers and portfolio risk management between defi and metals: Empirical evidence from the Covid-19. *Resources Policy, 83*, Article 103672.

Apergis, N., Chatziantoniou, I., & Gabauer, D. (2023). Dynamic connectedness between COVID-19 news sentiment, capital and commodity markets. *Applied Economics, 55* (24), 2740–2754.
Bahloul, S., & Khemakhem, I. (2021). Dynamic return and volatility connectedness between commodities and Islamic stock market indices. *Resources Policy, 71*, Article 101993.
Bakas, D., & Triantafyllou, A. (2020). Commodity price volatility and the economic uncertainty of pandemics. *Economics Letters, 193*, Article 109283.
Balcilar, M., Hammoudeh, S., & Asaba, N.-A. F. (2015). A regime-dependent assessment of the information transmission dynamics between oil prices, precious metal prices and exchange rates. *International Review of Economics and Finance, 40*, 72–89.
Batten, J. A., Ciner, C., & Lucey, B. M. (2015). Which precious metals spill over on which, when and why? Some evidence. *Applied Economics Letters, 22*(6), 466–473.
Boubaker, H., & Rezgui, H. (2020). Co-movement between some commodities and the Dow Jones Islamic index: A wavelet analysis. *Economics Bulletin, 40*(1), 574–586.
Bouri, E., Lucey, B., Saeed, T., & Vo, X. V. (2021). The realized volatility of commodity futures: Interconnectedness and determinants. *International Review of Economics and Finance, 73*, 139–151.
Cao, G., & Xie, W. (2022). Asymmetric dynamic spillover effect between cryptocurrency and China's financial market: Evidence from TVP-VAR based connectedness approach. *Finance Research Letters, 49*, Article 103070.
Cevik, E. I., Gunay, S., Zafar, M. W., Destek, M. A., Bugan, M. F., & Tuna, F. (2022). The impact of digital finance on the natural resource market: Evidence from DeFi, oil, and gold. *Resources Policy, 79*, Article 103081.
Chang, B. H., Sharif, A., Aman, A., Suki, N. M., Salman, A., & Khan, S. A. R. (2020). The asymmetric effects of oil price on sectoral Islamic stocks: New evidence from quantile-on-quantile regression approach. *Resources Policy, 65*, Article 101571.
Chowdhury, M. A. F., Abdullah, M., Alam, M., Abedin, M. Z., & Shi, B. (2023). NFTs, DeFi, and other assets efficiency and volatility dynamics: An asymmetric multifractality analysis. *International Review of Financial Analysis, 87*, Article 102642.
Corbet, S., Goodell, J. W., & Günay, S. (2022). What drives DeFi prices? Investigating the effects of investor attention. *Finance Research Letters, 48*, Article 102883.
Cunado, J., Gabauer, D., & Gupta, R. (2021). Realized volatility spillovers between energy and metal markets: A time-varying connectedness approach. *Financial Innovation, 10*, 12.
Diebold, F. X., & Yilmaz, K. (2012). Better to give than to receive: Predictive directional measurement of volatility spillovers. *International Journal of Forecasting, 28*(1), 57–66.
Fabozzi, F. J., Gupta, F., & Markowitz, H. M. (2002). The legacy of modern portfolio theory. *The Journal of Investing, 11*(3), 7–22.
Fasanya, I. O., Oliyide, J. A., Adekoya, O. B., & Agbatogun, T. (2021). How does economic policy uncertainty connect with the dynamic spillovers between precious metals and bitcoin markets? *Resources Policy, 72*, Article 102077.
Gubareva, M. (2021). Lower reversal limit of the European Central Bank deposit rate and sustainability of traditional banking business model. *Journal of Financial Economic Policy, 13*(6), 686–697.
Guesmi, K., Saadi, S., Abid, I., & Ftiti, Z. (2019). Portfolio diversification with virtual currency: Evidence from bitcoin. *International Review of Financial Analysis, 63*, 431–437.
Gupta, H., & Gupta, A. (2023). Investor's behaviour to COVID-19 vaccine: An event study on health and pharmaceutical sector in India. *International Journal of Pharmaceutical and Healthcare Marketing, 17*(4), 429–449.
Hammoudeh, S., & Yuan, Y. (2008). Metal volatility in presence of oil and interest rate shocks. *Energy Economics, 30*(2), 606–620.
Hasan, M. B., Rashid, M. M., Shafiullah, M., & Sarker, T. (2022). How resilient are Islamic financial markets during the COVID-19 pandemic? *Pacific-Basin Finance Journal, 74*, Article 101817.
Hassan, K., Hoque, A., & Gasbarro, D. (2019). Separating BRIC using Islamic stocks and crude oil: Dynamic conditional correlation and volatility spillover analysis. *Energy Economics, 80*, 950–969.
Husain, A., Karim, S., & Sensoy, A. (2024). Financial fusion: Bridging Islamic and green investments in the European stock market. *International Review of Financial Analysis, 94*, Article 103341.
Husain, S., Tiwari, A. K., Sohag, K., & Shahbaz, M. (2019). Connectedness among crude oil prices, stock index and metal prices: An application of network approach in the USA. *Resources Policy, 62*, 57–65.
Ji, Q., Bouri, E., Roubaud, D., & Shahzad, S. J. W. (2018). Risk spillover between energy and agricultural commodity markets: A dependence-switching CoVaR-copula modelAuthor links open overlay panel. *Energy Economics, 75*, 14–27.
Karkowska, R., & Urjasz, S. (2023). How does the Russian-Ukrainian war change connectedness and hedging opportunities? Comparison between dirty and clean energy markets versus global stock indices. *Journal of International Financial Markets Institutions and Money, 85*, Article 101768.
Katsiampa, P., Yarovaya, L., & Zięba, D. (2022). High-frequency connectedness between bitcoin and other top-traded crypto assets during the COVID-19 crisis. *Journal of International Financial Markets Institutions and Money, 79*, Article 101578.
Koop, G., Pesaran, M. H., & Potter, S. M. (1996). Impulse response analysis in nonlinear multivariate models. *Journal of Econometrics, 74*(1), 119–147.
Kumar, A., Iqbal, N., Mitra, S. K., Kristoufek, L., & Bouri, E. (2022). Connectedness among major cryptocurrencies in standard times and during the COVID-19 outbreak. *Journal of International Financial Markets Institutions and Money, 77*, Article 101523.
Lau, M. C. K., Vigne, S. A., Wang, S., & Yarovaya, L. (2017). Return spillovers between white precious metal ETFs: The role of oil, gold, and global equity. *International Review of Financial Analysis, 52*, 316–332.
Li, B., Haneklaus, N., & Rahman, M. M. (2024). Dynamic connectedness and hedging opportunities of the commodity and stock markets in China: Evidence from the TVP-VAR and cDCC-FIAPARCH. *Financial Innovation, 10*(1), 52.
Lin, B., & Su, T. (2020). The linkages between oil market uncertainty and Islamic stock markets: Evidence from quantile-on-quantile approach. *Energy Economics, 88*, Article 104759.
Lorente, D. B., Mohammed, K. S., Cifuentes-Faura, J., & Shahzad, U. (2023). Dynamic connectedness among climate change index, green financial assets and renewable energy markets: Novel evidence from sustainable development perspective. *Renewable Energy, 204*, 94–105.
Maghyereh, A. I., Abdoh, H., & Awartani, B. (2019). Connectedness and hedging between gold and Islamic securities: A new evidence from time-frequency domain approaches. *Pacific-Basin Finance Journal, 54*, 13–28.
Mensi, W., Hammoudeh, S., Al-Jarrah, I. M. W., Sensoy, A., & Kang, S. H. (2017). Dynamic risk spillovers between gold, oil prices and conventional, sustainability and Islamic equity aggregates and sectors with portfolio implications. *Energy Economics, 67*, 454–475.
Mensi, W., Selmi, R., & Al-Yahyaee, K. H. (2020). Switching dependence and systemic risk between crude oil and US Islamic and conventional equity markets: A new evidence. *Resources Policy, 69*, Article 101861.
Naeem, M. A., Peng, Z., Bouri, E., Shahzad, S. J. H., & Karim, S. (2022). Examining the asymmetries between equity and commodity ETFs during COVID-19. *Resources Policy, 79*, Article 103048.
Nagayev, R., Disli, M., Inghelbrecht, K., & Ng, A. (2016). On the dynamic links between commodities and Islamic equity. *Energy Economics, 58*, 125–140.
Nakajima, J. (2011). Time-Varying Parameter VAR Model with Stochastic Volatility: An Overview. *IMES Discussion Paper Series 11-E-09 of Methodology and Empirical Applications, Monetary and Economic Studies*. Institute for Monetary and Economic Studies, Bank of Japan.
Pesaran, H. H., & Shin, Y. (1998). Generalized impulse response analysis in linear multivariate models. *Economics Letters, 58*(1), 17–29.
Piñeiro-Chousa, J., López-Cabarcos, M.Á., Sevic, A., & González-López, I. (2022). A preliminary assessment of the performance of DeFi cryptocurrencies in relation to other financial assets, volatility, and user-generated content. *Technological Forecasting and Social Change, 181*, Article 121740.
Rejeb, A. B. (2017). On the volatility spillover between Islamic and conventional stock markets: A quantile regression analysis. *Research in International Business and Finance, 42*, 794–815.
Shao, X., Zhong, Y., Liu, W., & Li, R. Y. M. (2021). Modeling the effect of green technology innovation and renewable energy on carbon neutrality in N-11 countries? Evidence from advance panel estimations. *Journal of Environmental Management, 296*, Article 113189.
Sherif, M. (2020). The impact of coronavirus (COVID-19) outbreak on faith-based investments: An original analysis. *Journal of Behavioral and Experimental Finance, 28*, Article 100403.
Tiwari, A. K., Mukherjee, Z., Gupta, R., & Balcilar, M. (2019). A wavelet analysis of the relationship between oil and natural gas prices. *Resources Policy, 60*, 118–124.
Ugolini, A., Reboredo, J. C., & Mensi, W. (2023). Connectedness between DeFi, cryptocurrency, stock, and safe-haven assets. *Finance Research Letters, 53*, Article 103692.
Umar, Z., Aziz, S., & Tawil, D. (2021). The impact of COVID-19 induced panic on the return and volatility of precious metals. *Journal of Behavioral and Experimental Finance, 31*, Article 100525.
Umar, Z., Polat, O., Choi, S.-Y., & Teplova, T. (2022). The impact of the Russia-Ukraine conflict on the connectedness of financial markets. *Finance Research Letters, 48*, Article 102976.
Wu, F.-L., Zhan, X.-D., Zhou, J.-Q., & Wang, M.-H. (2023). Stock market volatility and Russia–Ukraine conflict. *Finance Research Letters, 55*, Article 103919.
Yarovaya, L., Elsayed, A. H., & Hammoudeh, S. (2021). Determinants of spillovers between Islamic and conventional financial markets: Exploring the safe haven assets during the COVID-19 pandemic. *Finance Research Letters, 43*, Article 101979.
Younis, I., Gupta, H., Du, A. M., Shah, W. U., & Hanif, W. (2024). *Spillover dynamics in DeFi, G7 banks, and equity markets during global crises: A TVP-VAR analysis*. Research in International Business and (Finance:102405).
Younis, I., Yousaf, I., Shah, W. U., & Longsheng, C. (2023). Risk transmission between equity market of China and its trading partners: New evidence from various financial crises. *International Journal of Emerging Markets*. https://doi.org/10.1108/IJOEM-11-2022-1763
Yousaf, I., Jareño, F., & Tolentino, M. (2023). Connectedness between Defi assets and equity markets during COVID-19: A sector analysis. *Technological Forecasting and Social Change, 187*, Article 122174.
Yousaf, I., & Yarovaya, L. (2022). Herding behavior in conventional cryptocurrency market, non-fungible tokens, and DeFi assets. *Finance Research Letters, 50*, Article 103299.
Yousaf, I., Youssef, M., & Gubareva, M. (2024). Return and volatility spillovers between non-fungible tokens and conventional currencies: Evidence from the TVP-VAR model. *Financial Innovation, 10*(1), 101.
Zeng, H., Lu, R., & Ahmed, A. D. (2023). Return connectedness and multiscale spillovers across clean energy indices and grain commodity markets around COVID-19 crisis. *Journal of Environmental Management, 340*, Article 117912.