TVP-VAR Analysis of NFT, DeFi, Assets, and Clean Energy in Investment Portfolio

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Abstract

Objective : This study explored the intricate connections between conventional investments, digital assets, and renewable energy in a rapidly changing financial environment that has been influenced by the COVID-19 pandemic, geopolitical tensions, and changing market trends. Analyzing these assets' interactions and evaluating their contribution to risk transmission and diversification were the goals.

Design/Methodology/Approach : This study analyzed daily return data encompassing a range of market situations from January 2, 2020, to January 2, 2023, using a time-varying parameter vector autoregression (TVP-VAR) model. The model captured dynamic interdependencies and spillover effects between asset types.

Findings : The results showed that financial markets were closely related to one another and that interactions were more intense during significant shocks. While digital asset markets, such as cryptocurrencies and NFTs, acted as shock receivers to varied degrees, crude oil emerged as the primary shock transmitter. The greatest susceptibility to market disruptions was shown by Bitcoin and Chainlink, whereas NFTs showed less vulnerability, confirming their usefulness as tools for portfolio diversification. The growing importance of clean energy assets in investment strategies was reflected in their increasing alignment with digital financial markets.

Practical Implications : By emphasizing the best asset allocation techniques during financial crises, the study offered insightful information to investors, asset managers, and legislators. NFTs and clean energy assets may improve portfolio resilience, according to the research, and regulatory frameworks ought to take into consideration the volatility spillovers of digital financial instruments.

Originality/Value : By combining clean energy equities, digital assets, and conventional investments into a single dynamic connectivity paradigm, this study added to the body of prior research. By highlighting the strategic significance of digital assets and sustainable investments in contemporary portfolio management, the study advanced knowledge of financial contagion.

Keywords : **non-fungible tokens (NFTs), clean energy, decentralized finance (DeFi), TVP-VAR; COVID-19, Russia-Ukraine conflict**

JEL Classification Codes : G110, G130, G150

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The interconnectedness of securities, commodities, and digital assets has been the subject of significant attention due to the financialization of digital and energy commodities and the integration of global financial markets (Sharma et al., 2024; Yadav et al., 2023). As digital assets such as non-fungible tokens (NFTs) and decentralized finance (DeFi) emerge as alternative investment platforms, the need to analyze their roles in portfolio management, particularly in times of heightened uncertainty, has become crucial (Chowdhury et al., 2023; Goodell et al., 2023). These assets are backed by blockchain and offer unique advantages in reducing

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volatility and managing risk, presenting new opportunities for diversification within investment portfolios (Kotishwar, 2020). Despite the growing interest in NFTs and DeFi, existing literature primarily focuses on their characteristics rather than their interconnectedness with traditional asset classes and their role in mitigating portfolio risk during crises. While studies have examined the potential of these digital assets to decouple from traditional markets, their dynamics during periods of geopolitical instability, economic downturns, or health crises remain underexplored.

The objective of this study is to bridge this gap by examining the connections between blockchain-based financial services, conventional assets (e.g., stocks, bonds, crude oil), and emerging sectors such as clean energy, particularly in the context of heightened instability, such as the periods marked by the occurrence of pandemic and geopolitical tensions. The research question centers on understanding how NFTs and DeFi assets interact with traditional assets and their potential role in reducing portfolio risk amidst these crises. This paper contributes to the literature by offering a comprehensive analysis of asset interdependencies and risk contagion dynamics during periods of global economic volatility.

Review of Literature

The literature on NFTs is limited but has evolved significantly in recent years due to their rapidly increasing sales volume and pricing relative to other digital assets. The origin, product structure, and market characteristics of NFTs are well explained in studies by Wang et al. (2021) and Wilson et al. (2022). Nadini et al. (2021) analyzed emerging NFTs, including art, utility, and gaming, with respect to trading volumes, structure, sales, market participants, and price forecasting. Emphasizing the requirement of a thorough knowledge of NFTs and their increasing importance in developing Web 3.0, Borri et al. (2022) underlined the special qualities of NFTs against traditional assets and cryptocurrencies. Dowling (2022a) noted that NFTs generally employ blockchain technology, which establishes a robust connection with cryptocurrencies. Another strand of literature focuses on the speculative bubbles observed in NFTs and DeFi assets. de Guzman (2022) identified the presence of infrequent but high-magnitude bubbles in NFTs and DeFi assets relative to conventional assets. These bubbles in digital assets can be attributed to financial distress situations, such as the pandemic, erratic trading volumes, and investor sentiment. Balaji et al. (2023) explored the use cases of NFTs, emphasizing their potential for digital creators in fields such as art, gaming, and entertainment. It highlights how NFTs provide secure transactions via blockchain, eliminate intermediaries, and enable artists to earn royalties from future sales. Fintech improves decision-making based on data, openness to data, and long-term development plans within organizations, according to Tao and Chao (2024), which in turn promotes corporate green investment in the energy industry.

A considerable body of academic literature exists on the descriptive elements of emerging cryptocurrencies (Gill et al., 2023; Narayanaswamy & Karthika, 2018) and the interconnectedness between cryptocurrencies, such as Bitcoin, Ethereum, and Ripple (Moratis, 2021), and the interconnectedness between different cryptocurrencies and NFTs (Ante et al. 2021; Dowling, 2022b; Karim et al., 2022). Dowling (2022b) examined the connectedness among NFTs and frequently traded cryptocurrencies, reporting the presence of co-movement between the two digital assets, although the spillover between them was limited. Ante (2023) also reported a significant impact of cryptocurrencies on NFT pricing, but the reverse impact was not observed. Karim et al. (2022) used the QVAR approach to examine the spillover between cryptocurrencies, DeFi, and NFTs, finding a lack of association between NFTs and crypto assets. This disconnection positions NFTs as strong candidates for portfolio diversification and minimizing volatility spillover among other financial assets.

Bani-Khalaf and Taspinar (2023) reported that the prices of NFTs and Bitcoin moved in tandem, but this co-movement was not apparent when the impact of the oil crisis was negated. The authors observed that small fluctuations in oil prices do not impact cryptocurrencies, while large changes can alter the co-movement

relationship. They are increasingly interested in the connection and volatility spillover involving digital assets and conventional investments. Studies indicate that DeFi and NFTs are promising portfolio diversifiers. The pandemic acted as a significant force in influencing the behavior of such assets and their interconnectedness. Regulators, investors, and portfolio managers can benefit from the more interconnected asset markets that emerged under COVID-19 (Gubareva, 2021; Pandey, 2023; Sharma et al., 2023). To optimize portfolio risks, cryptocurrencies can be utilized as portfolio components (Chopra & Saldi, 2022; Mills & Zeng, 2021). Patel et al. (2024) discovered a weak link between the cryptocurrency environment attention index and energy-efficient cryptocurrencies, alternative energy cryptocurrencies, and green traditional markets. This suggests that investors might reduce overall risk in their portfolios by diversifying with these types of assets.

The interconnectedness between NFTs and other asset classes and their implications for portfolio management has been the subject of extensive discussion and study as a result of the exponential increase in NFTs' trading volumes and market capitalization since 2021. The following results have been reported by recent studies, including those conducted by Aharon and Demir (2022), Umar et al. (2022), and Yousaf and Yarovaya (2022), which have investigated the spillover effects. Aharon and Demir (2022) discovered that there was no spillover from other assets, which implies that this lack of risk transmission can be leveraged for portfolio diversification. Nevertheless, the study did not consider the lead–lag relationships between assets and the varying time horizons. Yousaf and Yarovaya (2022) investigated the volatility contagion between conventional asset classes, including oil, bullion, Bitcoin, equity, DeFi, and NFTs. Umar et al. (2022) used the wavelet approach to investigate the correlation between the returns of NFTs and key assets (equities, gold, oil, Bitcoin, and bonds), and they reported comparable findings. In response to the pandemic and economic policy uncertainty, Liu et al. (2024) implemented the quantile frequency connectedness approach and the rolling window wavelet correlation to investigate the correlations and spillovers between NFTs and carbon markets. The results suggested that the carbon-NFT system experiences intense and rapid volatility spillover, which is characterized by a strong correlation between long-term returns. COVID-19 restricted the disproportionate spillover effect of carbon-NFTs, whereas economic policy uncertainty in China had favorable consequences. From 2019 to 2022, Bejaoui et al. (2023) examined the dynamic relationships between the stock markets of the BRICS and the Gulf states through the use of gold, cryptocurrencies, NFTs, and DeFi. The authors identified distinct correlations between stock markets and a variety of assets by employing the wavelet coherence approach. The relationships between emerging digital assets, cryptocurrencies, gold, and developing market indices are characterized by asymmetric patterns, particularly during significant political and health crises. Considerable evidence supports this assertion.

Duan et al. (2024) identified favorable correlations between energy-efficient and non-energy-efficient cryptocurrencies and both conventional and green financial assets. These linkages are influenced by cross-border trade between cryptocurrency marketplaces and the broader financial system, suggesting they may fluctuate significantly based on market conditions. Yousaf et al. (2024) discovered that NFTs serve as net transmitters of return and volatility spillovers, exerting a more pronounced influence on traditional currencies regarding return spillovers than on volatility shock transmissions, especially during the COVID-19 crisis when these spillovers markedly intensified. Recent literature underscores the increasing significance of NFTs and DeFi, as well as their connections to traditional assets, particularly in the context of recent crises like COVID-19 and geopolitical concerns. This changing environment highlights the necessity for additional research on the interrelation of digital assets with conventional asset classes, along with their function in portfolio diversification and risk reduction. By incorporating the most recent research, this review seeks to offer a more thorough analysis of the research issue and pinpoint important knowledge gaps regarding the dynamic interactions between these new digital assets and traditional investments.

Methodology and Data

The study is descriptive research in nature as it aims to examine the complex relationships and interconnections between conventional investments, cryptocurrencies, renewable energy, and digital assets in the context of variable market conditions. The objective of the investigation is to investigate the interaction between these assets over time, with a particular emphasis on market instability. The dynamic linkages among a variety of asset classes are investigated using the time-varying parameter approach from Antonakakis et al. (2020). Their approach is a continuation of the VAR-based connectedness method developed by Diebold and Yilmaz (2009, 2012, 2014).

The TVP-VAR (p) model is presented as follows:

$$X_t = \beta_t Y + \varepsilon_t, \varepsilon_t | \Omega_{t-1} \sim N(0, \Sigma_t) \quad (1)$$

$$\beta_t = \beta_t + \vartheta_t \vartheta_t | \Omega_{t-1} \sim N(0, R_t) \quad (2)$$

Equation 1 is written as a moving average equation on the basis of the Wold representation theorem and is presented as follows:

$$X_t = \sum_{j=0}^{\infty} \Theta_{kt} \varepsilon_{t-j} \quad (3)$$

Additionally, how the chosen variables are linked over time is presented by $D^{pH}{}_t = [d^{pH}{}_{ik,t}]$ and can be represented as follows:

$$d^{pH}{}_{ik,t} = \frac{\sigma^{-1}{}_{kk,t} \sum_{h=0}^{H-1} (e_i' \Theta_{h,t} \Sigma_t e_k)^2}{\sum_{h=0}^{H-1} (e_i' \Theta_{h,t} \Sigma_t \Theta'_{h,t} k)} \quad (4)$$

Wherein, $\sigma^{-1}{}_{kk,t}$ is the diagonal element of Σ_t. $d^{\sim pH}{}_{ik,t} = \frac{d^{pH}{}_{ik,t}}{\sum_{j=1}^{N} d^{pH}{}_{ik,t}}$ is normalized. The directional connectedness for a given pair of variables is defined as follows:

$NPDC^{pH}{}_{ik} = (d^{\sim pH}{}_{ki,t} - d^{\sim pH}{}_{ik,t}) \times 100$. When this expression has a value greater than zero, variable "i" governs variable "k" and true otherwise, too.

Data

This study uses daily closing prices of selected assets, including equities, bonds, renewable and non-renewable energy, DeFi, cryptocurrencies, and NFTs over the period from January 2, 2020, to February 2, 2023. The analysis focuses on two distinct sub-periods driven by significant global events that have shaped market dynamics. The first sub-period, from January 2, 2020, to February 23, 2022, captures the impacts of the COVID-19 pandemic, while the second sub-period, from February 24, 2022, to February 2, 2023, highlights the Russia–Ukraine crisis, both of which have profoundly influenced asset spillovers and interconnections (Gaio et al., 2022).

To represent equity markets, the MSCI ACWI Index is used, and for bond markets, the Bloomberg Barclays Global-Aggregate Total Return Index is utilized. Renewable energy is captured by the S&P Global Clean Energy Index and RENIXX World Index, with crude oil representing non-renewable energy. For DeFi, the study uses Chainlink, Maker, and Basic Attention Token. Daily NFT transaction prices are also included for a more detailed analysis. Price data for traditional asset classes and energy indices are sourced from Bloomberg, while DeFi and NFTs prices are gathered from investing.com and non-fungible.com. This robust dataset enables a granular examination of the evolving relationships between asset classes during key global crises.

Empirical Analysis and Results

Table 1 presents the descriptive statistics for daily returns of various asset classes during two distinct periods: the COVID-19 period and the Russia–Ukraine War period. During the COVID-19 period, most assets, except Maker, Basic Attention Token, and NFTs, had negative average returns ; whereas, in the Russia–Ukraine period, most assets had positive average returns, indicating a recovery or resilience in these markets. Variance, which measures the dispersion of returns, showed that NFTs had the highest variance in both periods, indicating high volatility. However, variance generally decreased in the Russia–Ukraine period compared to the COVID-19 period, suggesting reduced market volatility during the latter period. Positive skewness, which indicates a distribution with a longer right tail, was observed for most assets during the COVID-19 period, except for crude oil, which had a large negative skewness. In the Russia–Ukraine period, skewness was generally lower and less consistently positive. Excess kurtosis, indicating a distribution with heavy tails and peakedness, was significant for all assets in both periods, with notably high values for NFTs and cryptocurrencies during the COVID-19 period. The JB test statistics were highly significant ($p < 0.01$) for all assets in both periods, indicating that the returns are not normally distributed. Overall, the COVID-19 period exhibited higher volatility (variance) and more extreme deviations from normality (skewness and kurtosis) compared to the Russia–Ukraine period. NFTs and cryptocurrencies, such as Chainlink and Ethereum, displayed extreme volatility and non-normality, which is consistent with their nature as high-risk, high-reward assets (Khatri, 2024). Traditional assets like equities and bonds showed relatively lower variance and skewness, highlighting their comparatively stable nature during these periods of crisis.

Table 1. ***Descriptive Statistics***

	Equities	Bonds	S&P Clean Energy Index	RENIXX World Index	Chainlink	Maker	Basic Attention Token	Bitcoin	Ethereum	Crude Oil	NFT
COVID Period											
Average Returns	–0.025	0	–0.045	–0.09	–0.01	0.122	0.073	–0.176	–0.313	–1.215	13.561
Variance	1.722	0.086	4.986	6.285	81.171	93.348	64.414	27.174	49.869	464.736	5171.031
Skewness	1.817***	1.399***	0.909***	0.494***	2.790***	6.706***	2.002***	3.575***	3.018***	–19.815***	3.911***
Ex. Kurtosis	18.307***	11.373***	6.187***	1.885***	22.789***	104.827***	18.348***	42.198***	34.860***	425.393***	25.116***
JB	8069.801***	3177.713***	963.409***	104.896***	12752.386***	258737.190***	8170.686***	42436.851***	28996.960***	4228615.121***	16032.011***
Russia–Ukraine Conflict Period											
Average Returns	0.061	0.062	–0.011	–0.004	0.596	0.804	0.781	0.463	0.525	0.115	3.371
Variance	1.581	0.262	3.933	5.445	45.093	43.402	37.434	18.564	32.487	10.383	646.254
Skewness	–0.022	–0.450***	–0.287*	–0.094	1.512***	0.579***	1.296***	2.042***	2.088***	0.603***	1.416***
Ex. Kurtosis	0.396	1.304***	1.380***	1.638***	5.948***	5.574***	4.954***	11.054***	13.560***	1.381***	7.240***
JB	1.469	23.221***	20.652***	25.136***	411.854***	299.757***	289.154***	1284.544***	1862.039***	31.098***	559.054***

Notes. The table depicts the summary statistics of selected asset classes. Further, to check the normality of the return series, the Jarque–Bera (1980) was employed.

*, **, and *** are significant values at 10%, 5%, and 1%, respectively.

Table 2. ***Average Connectedness for the COVID-19 Period***

	Equities	Bonds	S&P Clean Energy	RENIXX	Chainlink	Maker	Basic Attention Token	Bitcoin	Ethereum	Crude Oil	NFT	FROM
Equities	32.44	3.21	19.29	12.88	6.53	8.39	8.15	7.67	0.64	0.51	0.29	67.56
Bonds	5.82	74.99	5.61	4.32	1.47	1.79	1.57	2.08	1.81	0.29	0.26	25.01
S&P Clean Energy	24	3.2	14.33	35.94	3.76	4.85	5.53	6.91	1.07	0.21	0.19	85.67
RENIXX	17.84	2.09	41.97	21.61	2.96	2.89	4.21	4.54	1.34	0.17	0.36	78.39
Chainlink	6.89	1.31	3.31	2.81	51.26	11.75	10.57	9.6	0.59	1.26	0.66	48.74
Maker	6.43	2.65	3.99	2.9	11.1	33.03	18.04	19.34	2.12	0.26	0.15	66.97
BAT	6.59	1.33	4.13	3.05	9.41	17.42	35.26	21.31	1.12	0.26	0.12	64.74
Bitcoin	6.3	2.1	5.27	3.44	9.4	19.41	22.11	30.12	1.48	0.18	0.18	69.88
Ethereum	1.4	0.58	2.12	2.5	0.77	1.83	1.45	2.07	86.69	0.21	0.38	13.31
Crude Oil	1.36	0.7	0.73	1.37	1.92	0.6	2.86	1.66	1.65	86.56	0.58	13.44
NFT	0.88	0.18	3.28	3.46	2.18	0.41	0.86	0.67	0.34	0.13	87.6	12.4
TO	77.5	17.34	89.7	72.67	49.5	69.34	75.35	75.86	12.17	3.49	3.17	546.08
NET	**9.94**	**–7.67**	**4.04**	**–5.72**	**0.76**	**2.37**	**10.6**	**5.98**	**–1.14**	**–9.95**	**–9.22**	**49.64**

Note. The table above illustrates the interconnectedness of the selected assets' return series for the pandemic period spanning from January 2, 2020 – February 23, 2022.

Table 2 presents static connectedness results for the returns of equity, bonds, clean energy, cryptocurrency, DeFi, and NFTs over the pandemic period. Table 3 depicts the static connectedness measures for the post-pandemic period spanning the Russia–Ukraine war, respectively. The off-diagonal figures in the tables represent static pairwise connectedness between the selected assets. The Tables elucidate the average connectedness among various financial assets during two distinct periods: the COVID-19 pandemic (January 2, 2020–February 23, 2022) and the Russia–Ukraine War period (February 24, 2022–January 2, 2023). Connectedness, represented as a percentage, indicates the degree to which fluctuations in one asset's returns affect others, providing valuable insights into the interdependencies within financial markets.

In Table 2, which covers the COVID-19 pandemic period, the rows and columns denote the originating and receiving assets, respectively. The diagonal elements reflect self-connectedness, signifying the influence of an asset on itself. Notably, equities exhibit substantial self-influence (32.44%) and exert significant influence on other assets, such as S&P Clean Energy (19.29%). Bonds predominantly influence themselves (74.99%) and have relatively minor impacts on other assets. Cryptocurrencies, including Bitcoin and Ethereum, display notable interconnectedness, influencing and being influenced by other assets within the network. The "TO" column aggregates the outward influence of each asset, while the "FROM" row sums the received influence, with the "NET" column indicates the net position of each asset as either a net influencer or receiver.

Table 3, which illustrates the Russia–Ukraine War period, continues to exhibit a comparable framework; however, it indicates modifications in interconnectedness patterns. During this period, equities demonstrate a substantial outward influence (71.37%) and an increased self-influence (38.59%), underscoring their significant role in the financial network. A wide array of assets is influenced by Bitcoin, which continues to play a critical role (78.45% TO). Cryptocurrencies continue to play a critical role. Furthermore, the geopolitical context impacts the distinct market behaviors of crude oil and NFTs, which are characterized by a high degree of self-connection. These tables collectively emphasize the dynamic nature of financial markets, in which the interconnectedness among assets fluctuates in response to significant global events. While cryptocurrencies demonstrate

Table 3. ***Average Connectedness for the Russia-Ukraine War Period***

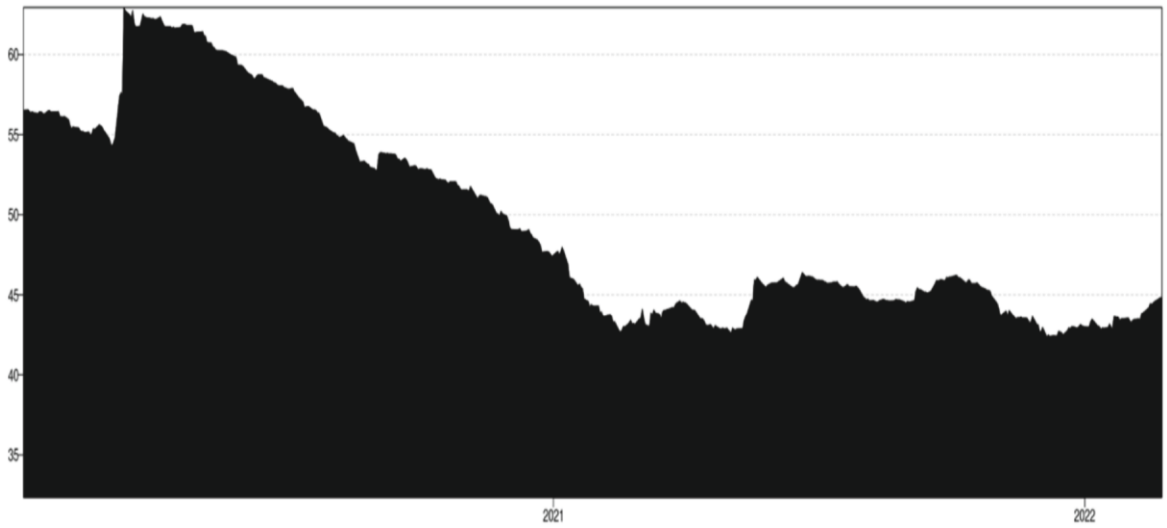
	Equities	Bonds	S&P Clean Energy	RENIXX	Chainlink	Maker	Basic Attention Token	Bitcoin	Ethereum	Crude Oil	NFT	FROM
Equities	38.59	4.41	12.46	6.42	7.28	8.66	9.35	11.46	0.77	0.22	0.38	61.41
Bonds	9.2	67.65	7.75	2.88	1.29	2.42	3.1	3.56	0.52	1.31	0.33	32.35
S&P Clean Energy	15.32	5.78	12.33	33.11	5.83	6.6	8.23	10.1	1.67	0.54	0.48	87.67
RENIXX	9.79	3.31	41.16	15.71	4.87	6.47	5.96	8.49	1.75	1.95	0.54	84.29
Chainlink	7.25	0.9	4.53	3.32	28.38	15.34	20	18.4	1.75	0.06	0.08	71.62
Maker	7.49	1.3	4.41	3.63	14.65	32.79	15.09	17.83	2.19	0.42	0.21	67.21
BAT	9.25	1.96	5.93	3.54	19.03	15.34	21.87	19.88	2.87	0.16	0.18	78.13
Bitcoin	9.98	2.09	7	5.21	16.22	16.53	18.35	21.55	2.72	0.26	0.09	78.45
Ethereum	0.89	0.51	1.91	1.98	1.62	2.45	3.66	3.51	82.88	0.32	0.26	17.12
Crude Oil	0.97	1.38	2.6	6.46	0.2	1.46	1.07	0.84	0.98	83.55	0.49	16.45
NFT	1.23	0.67	0.93	1.14	0.41	0.46	0.56	0.44	0.27	1.62	92.28	7.72
TO	71.37	22.3	88.67	67.68	71.38	75.72	85.36	94.51	15.49	6.86	3.05	602.4
NET	**9.96**	**–10.04**	**1**	**–16.6**	**–0.24**	**8.51**	**7.23**	**16.07**	**–1.62**	**–9.59**	**–4.67**	**54.76**

Note. The above table depicts the average static connectedness of the selected assets' return series for the Russia–Ukraine conflict period.

considerable interconnectedness, equities consistently emerge as influential assets, underscoring their increasing importance in the financial ecosystem. The differences between the two periods are indicative of changes in market dynamics, which were influenced by the distinct circumstances of the COVID-19 pandemic and the Russia–Ukraine conflict, respectively. This analysis contributes to the broader discussion of financial market behavior during periods of crisis by offering a comprehensive understanding of asset interdependencies.

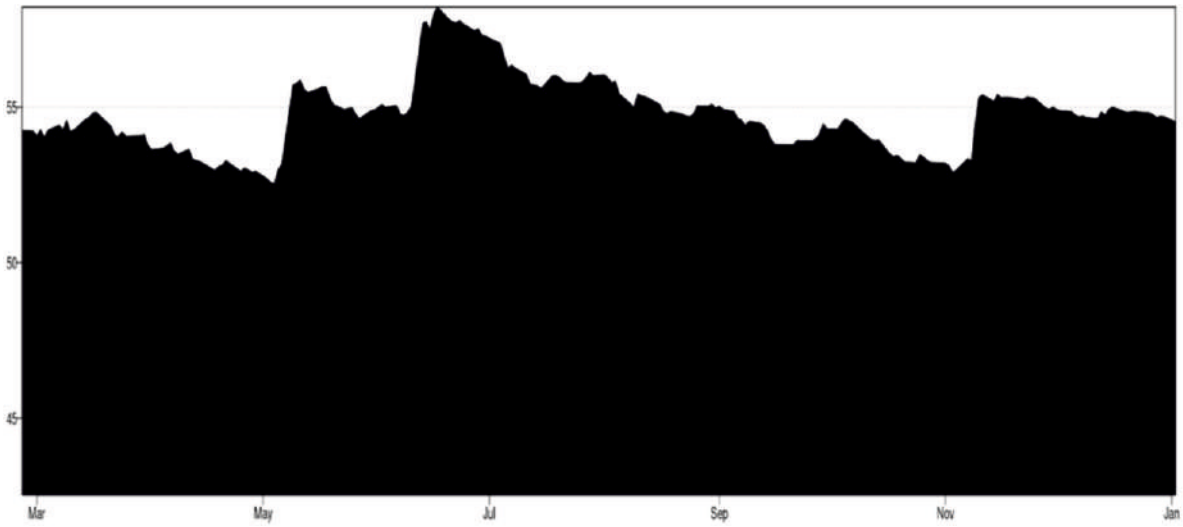
Figure 1 illustrates the total connectedness index (TCI) and net connectedness for asset returns during the

Figure 1. ***COVID-19 Period Index for Total Connectedness***



Note. The figure presents the aggregate connectedness index among the system variables for the COVID-19 period.

Figure 2. ***Total Net Connectedness of the Returns for the COVID-19 Period***



Note. The figure illustrates the overall net connectedness of returns for the chosen assets during the pandemic period.

COVID-19 pandemic. This coincided with the World Health Organization's declaration of the novel coronavirus outbreak as a pandemic on March 11, 2020, as the TCI reached its apogee in early 2020. The index subsequently experienced a gradual decline, culminating in its lowest position in early 2021. The world's adaptation to the new normal, characterized by social distancing, hybrid work models, and the increased utilization of technology-supported platforms and services, and the global vaccination efforts are the reasons for this decline.

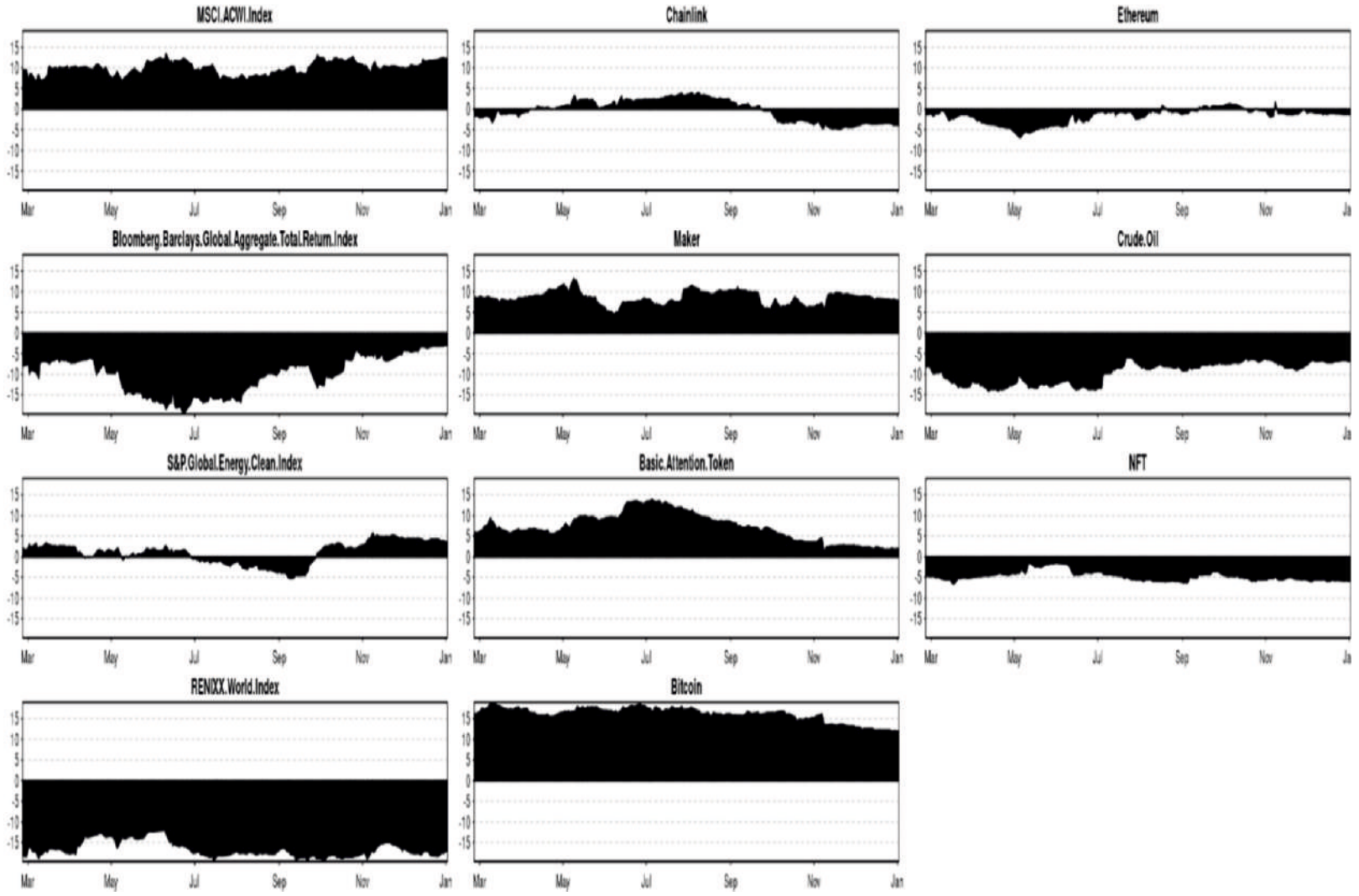
The net connectedness of return series during the COVID-19 period is illustrated in Figure 2. Equities, Maker, S&P Global Clean Energy, BAT, and Bitcoin were identified as net shock transmitters. Conversely, the RENIXX Clean Energy Index, NFTs, and bonds continued to function as net recipients of shocks throughout the pandemic. It is important to note that crude oil, which had been a net recipient of shocks prior to the COVID-19 period, maintained its status as a net receiver during the pandemic.

Figure 3 illustrates the total connectedness index (TCI) for the return series spanning from February 24, 2022, to January 2, 2023. The connectedness peaked in June–July 2022, coinciding with intensified Russian military offensives in various regions of Ukraine. This escalation led to increased volatility in the supply and prices of energy, food, and agricultural commodities. The energy sector was particularly impacted due to Russia's significant role as a major exporter of coal, gas, and oil. The conflict-induced sanctions heightened the demand for clean energy alternatives, driving the growth of the renewable energy industry (Mathis & Wade, 2022). Organizations worldwide identified successful prospects for low-carbon transitions (Liu et al., 2022). The conflict negatively affected equity markets (Boubaker et al., 2022), macroeconomic stability (Tong, 2024), and cryptocurrency performance (Khalfaoui et al., 2023).

Figure 4 outlines the net connectedness of the return series during this period. Bonds, Ethereum, crude oil, the RENIXX World Index, and NFTs are identified as net receivers of shocks. Conversely, equities, Maker, BAT, and Bitcoin are recognized as net transmitters of shocks. Chainlink and the S&P Clean Energy Index exhibit mixed results, displaying characteristics of both transmitters and receivers of shocks during the analyzed period.

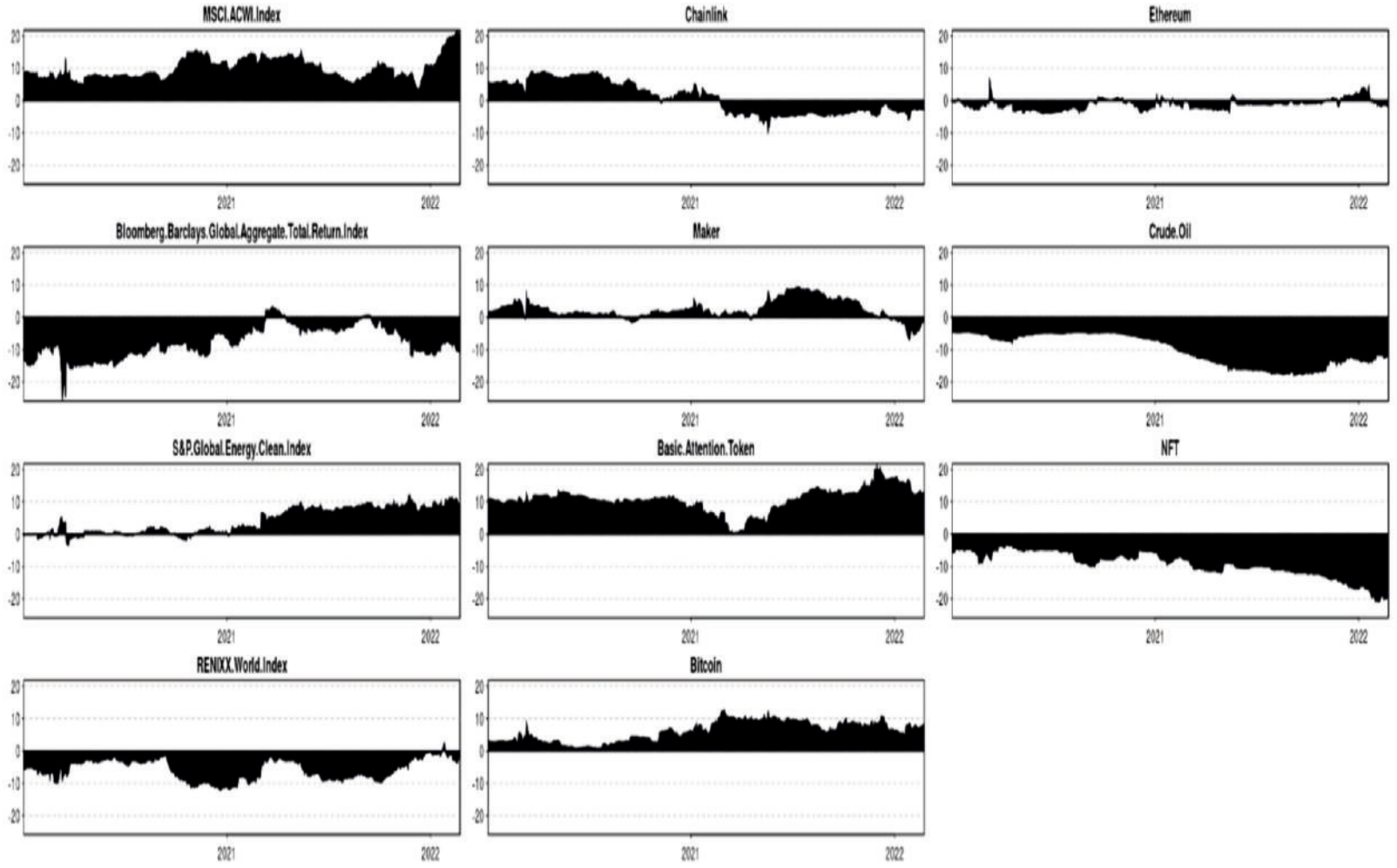
Figures 5 and 6 present network diagrams depicting the net pairwise connectedness within the financial system, focusing on selected assets such as equities, bonds, energy, and digital assets over the entire period and specific sub-periods. Consistent patterns emerge from Figures 5 and 6. Equities, S&P Clean Energy, and DeFi assets are consistently net transmitters of shocks across all sub-periods considered. Conversely, NFTs, crude oil,

Figure 3. ***Total Connectedness Index During the Russia-Ukraine War Period***



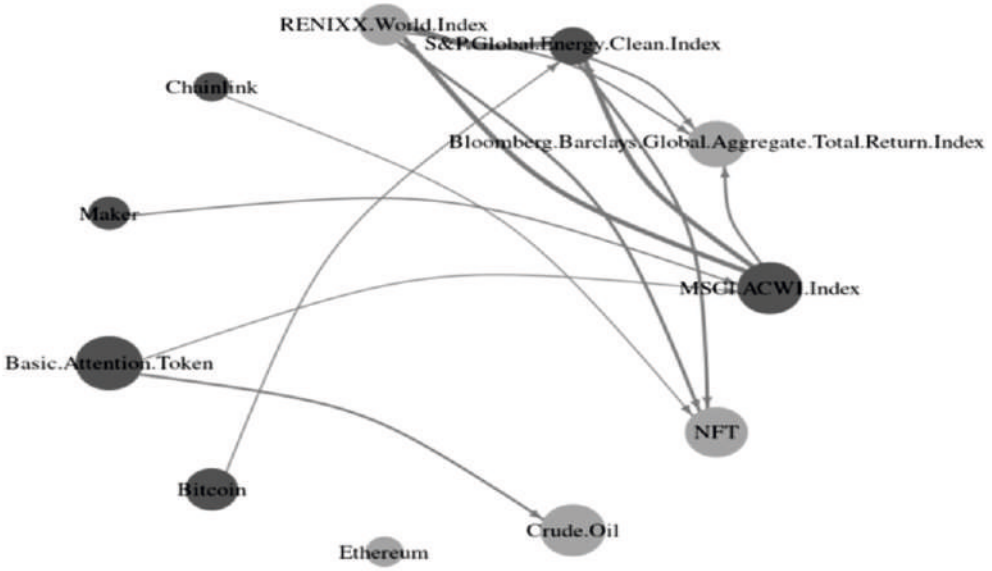
Note. The figure presents the TCI among the system variables for the Russia-Ukraine conflict period.

Figure 4. ***Total Return Net Connectedness During the Russia-Ukraine Conflict***



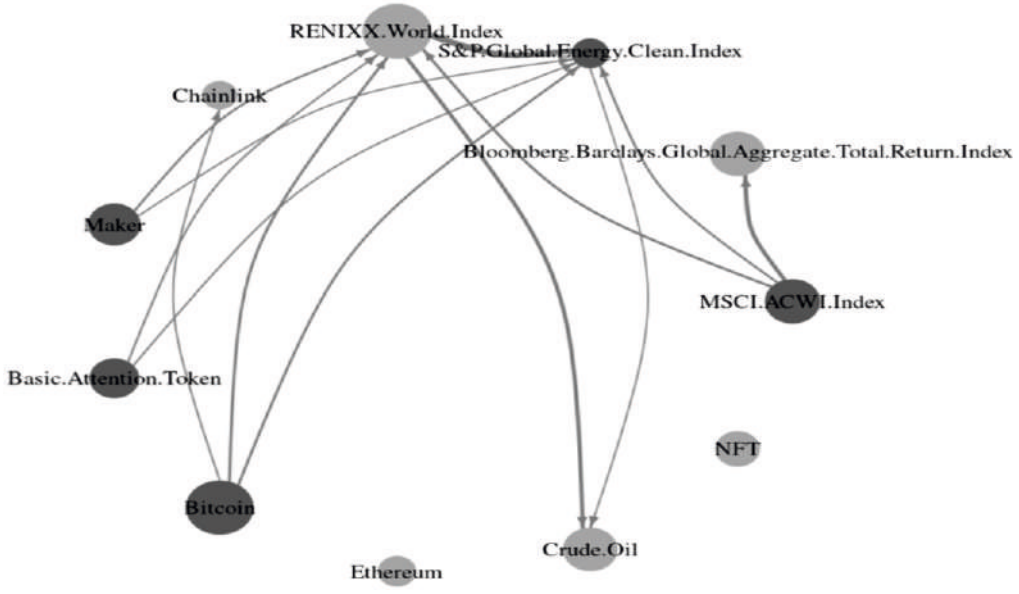
Note. The figure depicts the overall level of interconnectivity of returns for the selected assets during the war period of the Russia-Ukraine conflict.

Figure 5. ***Network Diagram of Net Spillovers for the COVID Period***



Note. The figure depicts the net spillovers that occurred among the selected assets during the pandemic. Black nodes signify assets acting as transmitters of shocks, whereas white nodes denote assets serving as net receivers. The size of the node is a weighted mean of the overall interconnectivity of the specified assets.

Figure 6. ***Network Diagram of Net Spillovers During the War Between Ukraine and Russia***



Note. The figure depicts the net spillovers that occurred among the selected assets during the war period between Russia and Ukraine. Black nodes signify assets acting as transmitters of shocks, whereas white nodes denote assets serving as net receivers. The size of the node is a weighted mean of the overall interconnectivity of the specified assets.

bonds, and the RENIXX Clean Energy Index consistently function as net receivers of shocks. Among the assets, cryptocurrencies and NFTs exhibit the least connectedness within the system during the sub-periods analyzed. These findings align with the static connectedness results and are consistent with recent studies by Karim et al. (2022), Umar et al. (2022), and Yousaf et al. (2023).

Conclusion

The time-varying parameter vector autoregression (TVP-VAR) frequency interconnectedness approach is employed in this study to undertake an empirical investigation of dynamic spillovers among traditional assets, digital assets, renewable energy, and non-renewable energy from January 2, 2020, to January 2, 2023. Several significant insights are obtained from the analysis. Initially, asset connectedness is more pronounced during periods of uncertainty and contagion, with substantial increases having been observed during the Russia–Ukraine conflict and the COVID-19 pandemic. These events presented unprecedented challenges, enhancing inter-market connections and enabling the transmission of volatility across a variety of asset classes. Second, shock receivers are consistently exhibited by a limited number of digital, traditional, and energy assets across various sub-periods. Assets such as the RENIXX World Index, crude oil, bonds, and NFTs demonstrate limited connectedness, thereby preserving their independence from systemic disruptions. The findings have substantial implications for investors and portfolio managers who value stability amid turbulent periods. Third, NFTs are distinguished by the fact that intrinsic disruptions influence the majority of their return dynamics. Consequently, portfolio management is significantly affected. The potential of certain assets to serve as effective safeguards is emphasized by their consistent behavior as net receivers of shocks, even during extreme events. Integrating these assets into a portfolio may increase stability and reduce risk, underscoring the significance of comprehending asset interconnectedness in dynamic market conditions. This study emphasizes the importance of carefully allocating assets and managing risks in light of the changing global economic landscape.

Managerial, Theoretical, and Policy Implications

This research has significant managerial, theoretical, and policy implications for policymakers, financial analysts, and investment managers. The results show how traditional assets, digital assets (NFTs, DeFi), and investments in clean energy are becoming more interdependent, especially in times of crisis like COVID-19 and the conflict between Russia and Ukraine. The findings highlight the strategic benefit of adopting NFTs as a hedge against systemic shocks for investment managers. This is because NFTs are relatively isolated from broader market volatility. The significant risk spread from crude oil and DeFi assets calls for ways to rebalance assets on the go, which in turn emphasizes the importance of diversified portfolios that include both digital and traditional assets. The study also promotes the creation of structured financial products, such as ETFs, that incorporate digital assets and green energy equities to accommodate the changing preferences of investors.

By incorporating a time-varying approach to capture asset interdependencies under extreme volatility, theoretical contributions are generated through an extension of the Diebold and Yilmaz (2014) spillover framework. The findings contest previous claims that cryptocurrencies serve as safe havens, demonstrating their increased vulnerability to market shocks. This study supports the idea that different market segments exist by showing that NFTs have only small effects on other markets, which makes them a unique type of asset.

From a policy standpoint, the findings show the pressing necessity for targeted regulations on digital asset volatility spillovers, with particular attention to DeFi, which demonstrates increased interconnectedness. Clean energy and digital finance are becoming more connected. To encourage investments focused on the environment

and social good (ESG), we need rules that offer rewards like tax breaks and green funding options. Furthermore, central banks must recognize digital asset market fluctuations when formulating monetary policies, as their growing impact extends beyond niche financial segments into mainstream economic stability. This paper offers a framework for risk management, optimal asset allocation, and the design of future-oriented policies in the age of digital and sustainable finance by connecting theoretical advances with actual financial decision-making.

Limitations of the Study and Scope for Future Research

This study, despite its comprehensive examination of the dynamic relationships between conventional assets, digital assets (NFTs, DeFi), and renewable energy investments, is subject to a number of limitations. The analysis is limited to the daily closing prices from January 2, 2020, to January 2, 2023, which may not adequately represent intraday volatility and short-term market reactions. Initially, this limitation is present. Another limitation is that the study used the TVP-VAR model, which, although good at representing connection across time, might not take structural breaks and non-linear interactions into sufficient consideration. The dataset may neglect emerging assets with unique behaviors, as it primarily concentrates on widely recognized digital assets such as Bitcoin and Chainlink. The study only considers COVID-19 and the Russia–Ukraine war, and not other geopolitical and economic issues that may affect asset interconnectedness.

Expanding the dataset to encompass intraday data and emergent digital assets could offer more profound insights into the changing landscape of digital finance and short-term market dynamics for future research. Machine learning and regime-switching models can help explain complicated interdependencies. To further expand the findings' application, it would be beneficial to investigate the influence of regulatory changes and the impact of other noteworthy geopolitical events. In addition, comparative analyses conducted across various regions or economic zones may demonstrate how regional disparities affect asset behaviors. Finally, employing sentiment analysis or macroeconomic indicators could provide a more comprehensive understanding of the factors that influence asset connectedness during periods of crisis.

Author's Contribution

Dr. Nidhi Malhotra conceived the idea and developed the required quantitative design to undertake the empirical study. She extracted research papers with high repute, filtered these based on keywords, and generated concepts and codes relevant to the study design. She also verified the analytical methods and supervised the study. The numerical computations were also done by her using *R* software.

Conflict of Interest

The author certifies that she has no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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