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Return and volatility spillovers between non-fungible tokens and conventional currencies: evidence from the TVP-VAR model

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Abstract

This study investigates the static and dynamic return and volatility spillovers between non-fungible tokens (NFTs) and conventional currencies using the time-varying parameter vector autoregressions approach. We reveal that the total connectedness between these markets is weak, implying that investors may increase the diversification benefits of their multicurrency portfolios by adding NFTs. We also find that NFTs are net transmitters of both return and volatility spillovers; however, in the case of return spillovers, the influence of NFTs on conventional currencies is more pronounced than that of volatility shock transmissions. The dynamic exercise reveals that the returns and volatility spillovers vary over time, largely increasing during the onset of the Covid-19 crisis, which deeply affected the relationship between NFTs and the conventional currencies markets. Our findings are useful for currency traders and NFT investors seeking to build effective cross-currency and cross-asset hedge strategies during systemic crises.

Keywords: Non-fungible tokens, Conventional currencies, Static connectedness, Dynamic return and volatility spillovers, TVP–VAR model, Covid-19

Introduction

The world today is shifting from traditional wallets to digital wallets—software-based programs that securely save user payment information. Digital wallets can hold both digital currencies and cryptocurrencies (Jokić et al. 2019; Nadeem et al. 2021). A new phenomenon in the blockchain world is the so-called non-fungible tokens (NFTs) (Corbet et al. 2021; Cornelius 2021; Kong and Lin 2021; Nadini et al. 2021; Wang et al. 2021). Although NFTs have been around for some years, the market for digital art pieces, commemorative items, and other assets that now reside in the blockchain ecosystem exploded in 2021 (Aharon and Demir 2021). NFTs differ from digital coins because each digital coin is supposed to be indistinguishable from the other coin of the same cryptocurrency, while the main feature of NFTs is the uniqueness of each token, i.e., non-fungibility (Corbet et al. 2021; Nadini 2021; and the references therein). Each NFT is supported by an individual chain of ownership to track the specific asset. Generally speaking, NFT is a one-of-a-kind digital asset. Technically speaking, NFTs are digital

files that can carry any form of digital content, from visual art to music to game records, and can even contain access to physical content (Yousaf and Yarovaya 2022a, b). This new type of digital asset relies on blockchain and cryptocurrencies to keep track of digital ownership. NFTs represent a way to create a feeling of authenticity and a concept of scarcity in the crypto world by reducing otherwise infinite possibilities of copying, reediting, and unauthorized sharing. NFTs are a type of asset that can be bought with cryptocurrencies. NFTs and cryptocurrencies are the key elements in the world of blockchain (Xu et al. 2019). While both NFTs and cryptocurrencies use the same blockchain technology, they differ in their attributes, especially in their fungibility properties.

The NFTs market got an enormous boost after Christie's auction house sold a digital artwork last March titled "Everydays: The First 5,000 Days" made by digital artist Beeple for an astonishing $69.4 million (Jones 2021). Additionally, there have been more of these exorbitant transactions. However, one should be aware of the wash trading phenomena and exercise caution when dealing with NFT market dynamics (Le Pennec et al. 2021). Although spurious growth of the NFTs market has gained the attention of various market players, from mainstream companies to retail investors, many still struggle with adequate comprehension of the NFT expansion phenomenon. An accelerated development of the NFTs market has also been attracting the attention of scholars. We present a few pioneering papers that examined the principal characteristics (diversification, hedging safe-haven proprieties, connectedness, and pricing) of these recently emerged digital assets. Dowling (2021a) analyzed the efficiency of NFTs relative to pricing virtual real estate tokens under the brand name Decentraland, whereas Dowling (2021b) examined the linkage between the pricing patterns of NFTs and conventional cryptocurrencies. In particular, Dowling (2021b) documented a low volatility transmission between cryptocurrencies and three different NFT classes, although he acknowledged price co-movements between Ethereum and NFT markets.

However, the interrelations of NFT digital assets and major asset classes are not sufficiently covered in the literature, except for the study on connectedness by Aharon and Demir (2021) and Yousaf and Yarovaya (2021). Among several specific findings on risk spillovers between NFTs and equities, bonds, gold, oil, US dollar, and Ethereum, the former study concluded that NFTs are mainly independent of shocks from other asset classes and that NFTs absorbed risks during the COVID-19 pandemic. Yousaf and Yarovaya (2022a, b) examined the static and time-varying connectedness between NFTs and Defi assets with four major asset classes—gold, Bitcoin, stocks, and crude oil. Consistent with the conclusion by Aharon and Demir (2021) that overall connectedness increased during the COVID-19 pandemic, the findings by Yousaf and Yarovaya (2022a, b) provided empirical evidence that the dynamic return and volatility connectedness became higher not only during the initial phase of the COVID-19 pandemic but also during the cryptocurrency bubble of 2021.

In the same context, Yousaf and Yarovaya (2022a, b) investigated the static and dynamic herding behavior in three cryptocurrency classes—traditional cryptocurrencies, NFTs, and DeFi assets—during the most recent cryptocurrency bubble of 2021. Their results revealed that static herding analysis failed to demonstrate any evidence of herding, while time-varying herding was identified in conventional currencies and DeFi assets in short-term investment horizons. Furthermore, the asymmetric herding analysis

provided evidence of herding in DeFi assets during the low volatility days. More recently, Umar et al. (2022) examined the coherence between returns of NFTs and other major assets (Bitcoin, bonds, crude oil, and stocks) using the wavelet approach and focused on the impact of the COVID-19 pandemic on their connectedness. They found that the return coherence between NFTs and other assets was high (low) for the two-week-plus (below-two-weeks) investment horizons throughout the entire sample period, comprising pre-COVID and COVID subsamples. Hence, NFTs appear to absorb risk only in the short run for below-two-weeks horizons. Moreover, in a recent study, Wang (2022) examined the volatility spillover connectedness between the NFT attention index and other financial markets using the time-varying parameter vector autoregression (TVP-VAR) model of Diebold and Yilmaz (2012). The study found that the NFT attention index indicates that NFT markets are dominated by other financial markets, including cryptocurrency, equity, bond, commodity, forex, and gold markets, suggesting that the NFT market mainly acts as a volatility spillover receiver from other financial markets. Ante (2022) investigated the interconnections between NFT sales, NFT users, and the pricing of Bitcoin and Ether, finding that Bitcoin price shocks increase NFT sales, while Ether price shocks reduce the number of active NFT wallets.

Furthermore, a broad range of research has studied the diversification, efficiency, hedging, and safe-haven proprieties of conventional cryptocurrencies (Corbet et al. 2019; Umar and Gubareva 2020; Angerer et al. 2021; Jalal et al. 2021; Sebastião and Godinho 2021; Fang et al. 2022). Another stream of research has investigated the return and volatility spillover effects in the cryptocurrency market (Ji et al. 2019, Huynh 2019, Omane and Alagidede 2019, Gkillas et al., 2018, Toan et al. 2020, Moratis 2021, Tara 2022). Using different econometric approaches, these studies investigated the phenomena of spillover effects between crypto-markets and other financial markets, including commodities, stocks, and equity markets.

The nexus between NFTs and conventional currencies has not been yet duly addressed in the literature. Therefore, to extend previous work on NFTs assets, this study investigates the static and time-varying connectedness between NFTs and conventional currencies. It utilizes the "modern portfolio theory," which states that investors can diversify portfolio risk by investing in weakly connected assets (Markowitz 1952). The weak connectedness between various assets can be due to various micro and macro level features and conditions. NFTs and fiat currencies can be weakly connected because of many reasons. First, the nature of NFTs and fiat currencies are different in terms of their currency features, i.e., whereas NFTs are nonfungible, fiat currencies are fungible. Second, both are different in terms of control—the control over NFTs is mostly decentralized, whereas fiat currencies are centralized. Third, the value of NFTs is mainly derived from their underlying assets (digital assets, such as arts, game items, videos, music, and pictures), whereas the value of fiat currencies is mainly derived from macroeconomic factors. Finally, major fiat currencies are acceptable globally because they are legal tenders but NFTs' acceptance is limited. However, NFTs and fiat currencies have some similarities, e.g., both can be used as currencies for transactions. Based on the above differences, we hypothesize about the weak connectedness between NFTs and fiat currencies, supporting the modern portfolio theory. Although diversification does not entirely remove investment risk, it creates opportunities to optimize investment streams and attain

higher expected returns. Therefore, if we find weak connectedness between NFTs and conventional currencies, it implies the diversification benefit of adding NFTs to the conventional currency's portfolios and vice versa. This study offers new insights into the new digital NFT market and provides useful information to investors and portfolio managers, enabling them to build more profitable investment strategies by allocating funds between conventional currencies and NFTs.

In this context, we highlight that NFTs are different from conventional cryptocurrencies in terms of fungibility. This is because cryptocurrencies use fungible tokens, implying that they can be easily traded or exchanged for one another. Thus, investors can move rapidly from one cryptocurrency to another to adjust their allocations in response to market movements. However, in NFTs, every token is unique. In summary, NFTs are different from conventional cryptocurrencies, and it is important to investigate their connectedness with other traditional financial assets. As already mentioned above, in this study, we investigate the connectedness and risk spillovers between NFTs and conventional currencies.

The contribution of our study to the contemporaneous currency-related literature is twofold. First, to the best of the author's knowledge, this is the first study to examine the return and volatility spillovers between NFTs and conventional currencies. NFTs mainly belong to decentralized markets, whereas fiat currencies are centrally controlled by central banks. Therefore, this investigation also provides insights into the linkages between centralized and decentralized markets. In fact, previous research has explored the hedging and safe havens characteristics as well as the diversification benefits of cryptocurrencies against a range of traditional assets, including oil, gold, stock indices, and conventional currencies (Guesmi et al. 2019; Wang et al. 2019; Bouri et al. 2020; Conlon et al. 2020; Corbet et al. 2020; Shahzad et al. 2020; Umar and Gubareva 2020; Goodell and Goutte 2021; Mariana et al. 2021; Melki and Nefzi 2021; Yousaf et al. 2022). However, the results from these studies are mixed. Whereas most of these studies reported the hedging and safe-haven properties of cryptocurrencies against different financial market risks, others revealed that cryptocurrencies failed to provide hedging and diversification roles against market risks, especially during the COVID-19 market turmoil. In particular, Umar and Gubareva (2020) explored the impact of the COVID-19 pandemic on the volatility of currency and cryptocurrency markets, reporting that the cross-currency hedge strategy, which can work under normal market conditions, is likely to fail during crises, such as the COVID-19 pandemic. Therefore, it is important to search for other alternative assets that can provide hedging and diversification opportunities (Skeikh et al. 2020a, b; Asad et al. 2020; Umar et al. 2022) for currency traders and investors, which is the main motivation of this study—to explore the effectiveness of NFTs as alternative assets to conventional currencies.

Second, our study contributes to the ongoing literature on the response of the currency markets to the economic impacts of the COVID-19 pandemic. The "contagion effect" explains that the connectedness between markets became higher during the crisis and recession episodes because of panic and huge uncertainty in the market (King and Wadhwani 1990; Forbes and Rigobon 2002; Caporale et al. 2005). During the crisis, the contagion effect occurred because of various factors, including information asymmetry, herding behavior, and liquidity concerns. We hypothesize that there was a higher

connectedness between NFTs and fiat currency markets during the COVID-19 pandemic. In the existing literature, the phenomenon of return/volatility spillovers between different financial markets, including stocks, equities, bonds, currencies, and commodities markets, has been widely addressed, especially during financial distress and crises, such as the 2008 Global Financial Crisis and the recent COVID-19 pandemic (Baur 2010, Bayoumi and Bui 2012; Diebold and Yilmaz 2012; Hammoudeh et al. 2014, Ajmi et al. 2014, Tiwari et al. 2018; Reboredo et al. 2020; Bouri et al. 2021 Umar et al. 2021, Youssef et al. 2021; Jareno and Yousaf 2023; Ali et al. 2023; Yousaf et al. 2023). Further, the joint dynamics of conventional currencies and cryptocurrencies have been explored in the recent literature (Rehman et al. 2022); however, the connectedness between NFTs and fiat currencies during the COVID-19 pandemic has not been explored. Using a fresh sample period covering the most recent global crisis caused by the outbreak of the pandemic, our findings can provide useful insights for investors, traders, portfolio risk managers, and regulators in the currency and digital assets markets.

We test the static and dynamic spillover analysis using Diebold and Yilmaz's (2009, 2012, 2014) forecast error variance decomposition combined with TVP-VAR recently employed by Antonakakis and Gabauer (2017). Such an advanced approach has been broadly used in previous research (Mokni et al. 2020; Umar et al. 2021; Youssef et al. 2021) to investigate time-varying connectedness between different financial markets. This methodology substantially improves the connectedness approach of Diebold and Yilmaz (2014) by allowing the variances to vary over time through a Kalman filter estimation, which relies on decay factors. By doing so, the TVP-VAR approach overcomes the challenge of an arbitrarily chosen rolling window size, which can lead to very erratic or flattened parameters and result in a loss of valuable observations (Antonakakis and Gabauer 2017; Gabauer and Gupta 2018).

The main results of this study reveal a weak connectedness between NFTs and conventional currencies; therefore, investors can diversify their risk of conventional currency-based portfolios by adding NFT assets. Moreover, return and volatility spillovers between NFTs and conventional currencies varied over time and increased significantly during the onset of the pandemic-triggered crisis. During the COVID-19 outbreak, NFTs acted as net transmitters of return and volatility spillovers to the currency markets. In other words, conventional currencies acted as net recipients of spillovers from the NFTs market during the pandemic. These findings highlight that currency traders and investors may benefit from diversification opportunities by allocating portions of their funds to NFTs.

The remainder of the paper is structured as follows: Section "Methodology—the TVP-VAR-based approach" presents the methodology; Section "Data and descriptive statistics" provides the data and brief preliminary results; Section "Results and discussion" reports the empirical findings; and Section "Conclusion" concludes.

Methodology—the TVP-VAR-based approach

To explore the time-varying return and volatility transmission mechanism between NFTs and conventional currencies during the recent COVID-19-triggered crisis, we use the TVP-VAR framework introduced by Koop and Korobilis (2014) combined with the connectedness approach of Diebold and Yılmaz (2012, 2014) based on the

forecast-errors variance decomposition. We prefer the TVP-VAR framework over other competitive models (e.g., BEKK-GARCH, DCC-GARCH, and VAR-GARCH) because of its many advantages. The other competitive models have a few drawbacks, including the following: (a) these models cannot be used to estimate time-varying spillovers, and (b) it is sometimes difficult to do estimations through these models because of convergence issues (Bouri 2015; Arouri et al. 2012; Yousaf and Ali 2020). However, the TVP-VAR framework overcomes these issues of competitive models. Further, an important advantage of this methodology is that it allows the variances to vary over time via a Kalman filter estimation, which relies on decay factors. Thus, the TVP-VAR approach overcomes the shortcomings of arbitrariness related to a subjective choice of the rolling window size. Inappropriate size of the rolling window may lead to very erratic or flattened parameters and eventually cause a loss of valuable observations (Antonakakis and Gabauer 2017; Antonakakis et al. 2018; Gabauer and Gupta 2018; Korobilis and Yilmaz 2018). Finally, the TVP-VAR approach is even preferable to the Diebold and Yilmaz (2012, 2014) approach because there is no loss of valuable observations in this approach due to the rolling window (Korobilis and Yilmaz 2018; Yousaf and Yarovaya 2022b).

The TVP-VAR(1) model can be specified as follows:

$$Y_t = \Phi_t Y_{t-1} + u_t; u_t \backslash \Omega_{t-1} \backsim N(0, S_t), \tag{1}$$

$$\Phi_t = \Phi_{t-1} + \nu_t; \nu_t \backslash \Omega_{t-1} \backsim N(0, R_t), \tag{2}$$

where Y_t represents an $(N \times 1)$—dimensional array; Ω_{t-1} is the set of information available at $t-1$; Y_{t-1} stands for an $(Np \times 1)$—lagged vector of the dependent variables; Φ_t represents an $(N \times Np)$ matrix of the time-varying coefficients; u_t and ν_t are two $(N \times 1)$—dimensional arrays of the error terms; and S_t and R_t denote $(N \times N)$ and $(Np \times Np)$ time-varying variance–covariance matrices of the error terms u_t and ν_t, respectively. Regarding the estimation of the TVP-VAR parameters, we proceed by transforming the TVP-VAR to its vector moving average (VMA)—TVP-VMA. The time-varying parameters of the VMA are fundamental for calculating the connectedness index introduced by Diebold and Yılmaz (2012) through the generalized impulse response function and the generalized forecast error variance decomposition, pioneered by Koop et al. (1996) and Pesaran and Shin (1998). Hence, we rewrite Equation (1) in the following representation:

$$Y_t = \Phi_t Y_{t-1} + u_t = A_t u_t, \tag{3}$$

where $A_t = \begin{pmatrix} A_{1,t} & A_{2,t}, & \dots & A_{p,t} \end{pmatrix}'$ is an $(N \times N)$ matrix of parameters, for which $A_{i,t} = \sum_{k=1}^{p} \Phi_{1,t} A_{i-k,t}$ *if* $i \neq 0$ and I_N otherwise. Thus, the generalized impulse response function determines the responses of all variables after a shock in variable i.

The pairwise directional connectedness from j to i is presented by the generalized forecast error variance decomposition, $\Psi^{g}_{j,t}(J)$. It represents the influence variable j has on variable i in terms of its forecasts error variance share:

$$\Pi^{g}_{j,t}(J) = \frac{\sum_{t=1}^{J-1} \Psi^{2,g}_{ij,t}}{\sum_{j=1}^{N} \sum_{t=1}^{J-1} \Psi^{2,g}_{ij,t}}, \tag{4}$$

where $\Pi^{g}_{j,t}(J)$ denotes the variance share one variable has on others. $\Psi^{g}_{j,t}(J) = S^{-\frac{1}{2}}_{jj,t} A_{J,t} S_t u_{j,t}$, $\sum_{j=1}^{N} \Pi^{N}_{j,t}(J) = 1$, and $\sum_{i,j=1}^{N} \Pi^{N}_{j,t}(J) = N$.

We proceed to construct the total connectedness index (TCI), which permits assessing the interconnectedness of the considered system. This methodology illustrates how a shock on one parameter spills over to other parameters and may be represented as follows:

$$H^{g}_{t}(J) = \frac{\sum_{i,j=1, i\neq j}^{N} \Pi^{g}_{ij,t}(J)}{N} \times 100. \tag{5}$$

The directional spillover that an element i receives from all other elements j, also called the *total directional connectedness from others*, is expressed as follows:

$$H^{g}_{i\leftarrow j,t}(J) = \frac{\sum_{i,j=1, i\neq j}^{N} \Pi^{g}_{ij,t}(J)}{\sum_{j=1}^{N} \Pi^{N}_{ij,t}(J)} \times 100. \tag{6}$$

Similarly, we define the directional spillover that element i transmits to all other elements j, also called the *total directional connectedness to others*, as follows:

$$H^{g}_{i\rightarrow j,t}(J) = \frac{\sum_{i,j=1, i\neq j}^{N} \Pi^{g}_{ji,t}(J)}{\sum_{j=1}^{N} \Pi^{N}_{ji,t}(J)} \times 100. \tag{7}$$

Now, we calculate the net pairwise directional spillover by subtracting the total directional spillover to others from the total directional spillover from others. This net pairwise spillover represents the influence exerted by element i on the considered system.

$$H^{g}_{i,t}(J) = H^{g}_{i\rightarrow j,t}(J) - H^{g}_{i\leftarrow j,t}(J). \tag{8}$$

If $H^{g}_{i,t}(J) > 0$, it signifies that element i impacts the system more than it is impacted by it. On the contrary, if $H^{g}_{i,t}(J) < 0$, then element i is driven by the system.

Data and descriptive statistics

This study applies the TVP-VAR model to investigate the return and volatility spillover between NFTs and conventional currencies. We compile a daily dataset of four major NFTs—THETA (THETA), XTZ (Tezos), ENJ (Enjin Coin), and MANA (Decentraland)—and four major conventional currencies—CNY (Chinese Yuan), JPY (Japanese Yen), EUR (Euro), and GBP (Pound Sterling). The sample period starts from January 19, 2018 and ends on October 26, 2021.

Table 1 reports the summary statistics for the daily changes in the returns of the NFTs and the conventional currencies. The average returns of NFTs are higher than the returns of conventional currencies, except for XTZ. The highest average return is exhibited by THETA. Regarding unconditional volatilities, NTFs are riskier than conventional currencies. We observe that ENJ has the highest risk, while the Chinese Yuan has the lowest average volatility. In general, compared with conventional currencies, NFTs provide higher returns with higher risk. Summarizing the findings in Table 1, we highlight that the return-risk binominals of the analyzed NTFs are significantly different from those of the conventional currencies.

Table 1 Descriptive statistics

	Non-Fungible Tokens				Conventional Currencies			
	THETA	XTZ	ENJ	MANA	CNY	JPY	EUR	GBP
Mean	0.00322	−0.00113	0.00289	0.00050	0.00000	− 0.00003	− 0.00005	− 0.00001
Max	0.51053	0.25986	0.76823	0.50067	0.01416	0.02822	0.01387	0.02691
Min	− 0.60387	− 0.60726	− 0.62423	− 0.62984	− 0.01580	− 0.03154	− 0.02064	− 0.03718
S.D.	0.08361	0.07494	0.08837	0.07642	0.00265	0.00427	0.00398	0.00545
Skew	− 0.02578	− 0.91714	1.32551	− 0.23101	− 0.20222	− 0.52964	− 0.23572	− 0.14784
Kurt	10.1565	10.4266	19.2917	11.3248	6.9594	12.6423	4.4393	6.5652
J-B	2097.80	2396.81	11159.05	2847.25	648.78	3854.05	93.95	524.19
ARCH	4.63106[a]	32.0665[a]	3.12942[c]	40.2238[a]	14.1542[a]	147.9523[a]	9.94682[a]	46.5038[a]
Q-stat	30.513[b]	35.9980[a]	27.773[b]	33.7080[a]	28.588[a]	41.4350[a]	33.6620[a]	36.5990[a]
ADF	− 20.829[a]	− 33.7242[a]	− 33.950[a]	− 34.6951[a]	− 34.2924[a]	− 33.7020[a]	− 30.5662[a]	− 29.2934[a]

Max—Maximum, Min—Minimum, S.D.—Standard deviation, Skew—Skewness, Kurt—Kurtosis, J–B—Jarque–Bera, ADF—Augmented Dicky Fuller test. [a,b,c]denote, respectively, the 1, 5, and 10% level of significance

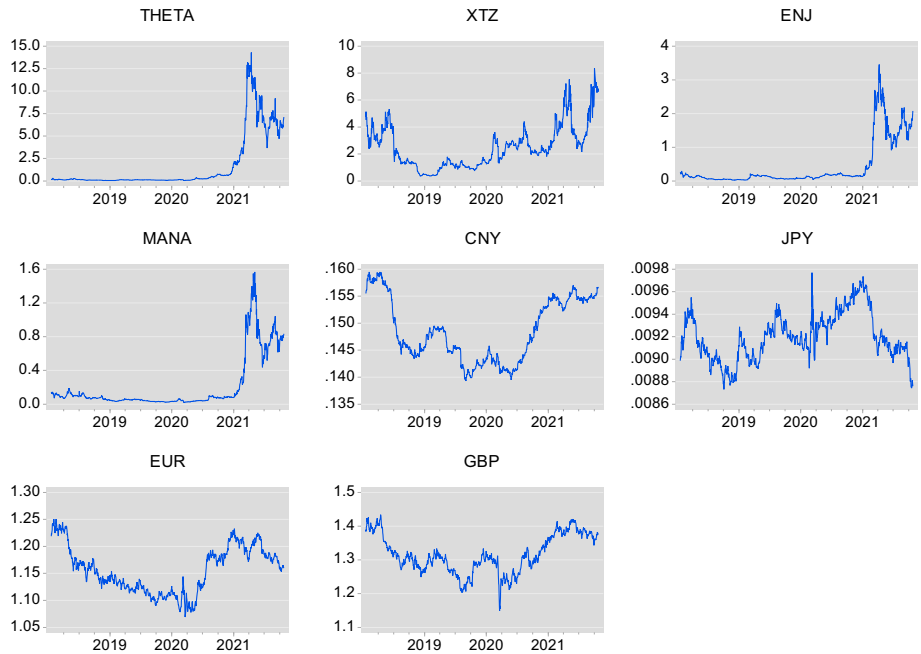

Fig. 1 Prices of NFTs and conventional currencies (2018–2021)

The returns on both NFTs and conventional currencies are skewed to the left, as highlighted by the negative and significant skewness values, except ENJ. Based on the kurtosis values, we notice that all return series for NFTs and currencies are characterized by excess kurtosis, suggesting leptokurtic distributions with fat tails. The null hypothesis of normality is rejected for all series at the 1% level, as indicated by the Jarque–Bera test. The Augmented Ducky–Fuller test results reveal evidence of the absence of unit roots in all series.

Figure 1 depicts the time dynamics of asset prices. We notice that the prices of all NFTs, except XTZ, are around zero before jumping to their all-time highs in the first quarter of 2021. After these hikes, the prices of NFTs declined, exhibiting fairly

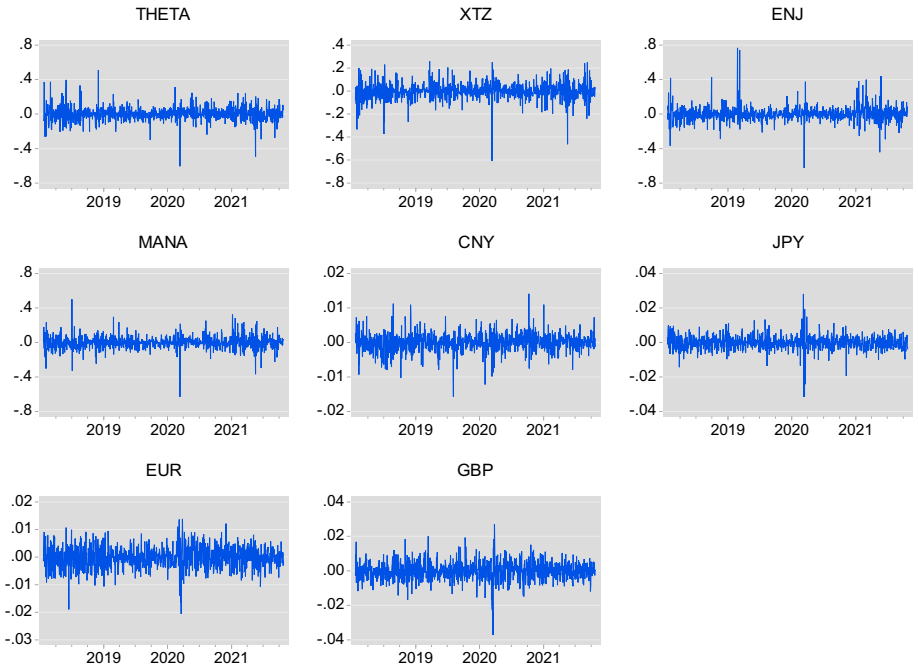

Fig. 2 Returns of NFTs and conventional currencies (2018–2021)

Table 2 Unconditional correlations

	Non-fungible tokens				Conventional currencies			
	THETA	**XTZ**	**ENJ**	**MANA**	**CNY**	**JPY**	**EUR**	**GBP**
THETA	1.00							
XTZ	0.47	1.00						
ENJ	0.53	0.47	1.00					
MANA	0.51	0.50	0.61	1.00				
CNY	0.07	0.03	0.06	0.07	1.00			
JPY	0.00	− 0.05	− 0.07	− 0.05	0.08	1.00		
EUR	0.06	0.04	0.03	0.06	0.30	0.44	1.00	
GBP	0.11	0.07	0.04	0.08	0.29	0.31	0.60	1.00

CNY—Chinese Yuan, JPY—Japanese Yen, EUR—Euro, GBP—Pound Sterling

volatile downtrends. Regarding conventional currencies, we find that for all currencies, except JPY, prices declined from the beginning of the sample period until mid-2020. From the second half of 2020 onward, all the currencies recovered and then maintained their price levels above the COVID-19 crisis lows.

Figure 2 illustrates the returns dynamic for NFTs and conventional currencies, which reveals the volatility clustering in all markets during different timeframes. However, the highest peaks of volatility were in the first quarter of 2020. This finding highlights that the NFTs and currency markets were considerably affected by the outbreak of the COVID-19 pandemic.

Table 2 reports the unconditional correlations between NFTs and conventional currencies, which reveal weak positive correlations between NFTs and CNY, EUR, and

GPB but weak negative correlations with JPY. These results highlight that investors may wish to add NFTs to their currencies-based portfolios to benefit from diversification due to almost unsynchronized asset dynamics.

Results and discussion

In this section, first, we analyze the static return and volatility spillovers of NFTs and conventional currencies. Second, we investigate the dynamic spillovers within the analyzed framework.

Static return and volatility spillover

Table 3 reports the static return spillovers between NFTs and conventional currencies. As presented in the table, the TCI is 41.02%, indicating that during the research period, on average, the total connectedness within the considered NFTs-currencies system was moderate. The rightmost column "FROM others" reports the amount of return spillovers emitted from the system to each market. Our findings reveal that MANA and ENJ received the highest return spillovers from the system, receiving 45.03% and 44.68%, respectively. These tokens are followed by EUR (42.26%), JPY (42.24%), and THETA (42.18%). The lowest amounts of return spillovers are transmitted from the system to GBP (34.17%), XTZ (38.23%), and CNY (39.38). In addition, analyzing the spillovers not from the entire system but from NFTs to currencies reveals that the influence of NTFs on the currency market returns is weak.

The row "TO others" presents the return spillovers from each market to the system. The results reveal that JPY (50.45%), MANA (49.44%), and ENJ (48.65%) are the highest transmitters of return spillovers to the system. The lowest return spillovers received by the system are from GBP (20.17%) and CNY (35.16%). In addition, analyzing the spillovers from conventional currencies to NFTs but not to the entire system reveals that NFTs returns are weakly affected by conventional currencies; hence, the returns of the currency markets are not effective predictors of NFTs returns. Moreover, comparing the two shadowed areas of Table 3, we conclude that although the interrelation of the

Table 3 Static return spillovers

	Non-fungible tokens				Conventional currencies				FROM others
	THETA	XTZ	ENJ	MANA	CNY	JPY	EUR	GBP	
THETA	57.82	11.45	15.01	13.86	0.27	0.39	0.56	0.64	42.18
XTZ	11.55	61.77	12.08	13.63	0.24	0.31	0.16	0.26	38.23
ENJ	14.30	11.33	55.32	18.13	0.32	0.23	0.12	0.25	44.68
MANA	13.14	12.59	18.11	54.97	0.32	0.34	0.22	0.30	45.03
CNY	0.63	0.68	0.70	0.74	60.62	19.58	9.60	7.45	39.38
JPY	0.77	0.93	0.90	1.13	15.27	57.76	20.59	2.65	42.24
EUR	0.80	0.57	0.47	0.72	7.75	23.34	57.74	8.61	42.26
GBP	1.41	1.39	1.38	1.21	10.99	6.27	11.52	65.83	34.17
TO others	42.60	38.95	48.65	49.44	35.16	50.45	42.76	20.17	328.18
Inc. own	100.42	100.71	103.97	104.41	95.78	108.21	100.50	86.00	TCI
NET	0.42	0.71	3.97	4.41	-4.22	8.21	0.50	-14.00	41.02

CNY—Chinese Yuan, JPY—Japanese Yen, EUR—Euro, GBP—Pound Sterling

Table 4 Static volatility spillovers

	Non-fungible tokens				Conventional currencies				FROM others
	THETA	XTZ	ENJ	MANA	CNY	JPY	EUR	GBP	
THETA	67.62	8.34	11.37	10.26	0.61	0.54	0.45	0.82	32.38
XTZ	7.80	68.42	9.08	13.77	0.17	0.14	0.26	0.36	31.58
ENJ	10.13	8.24	65.95	13.17	0.53	0.62	0.78	0.58	34.05
MANA	9.21	13.44	13.92	62.52	0.21	0.14	0.20	0.36	37.48
CNY	0.63	0.38	0.68	0.53	46.51	21.44	18.00	11.83	53.49
JPY	0.57	0.66	0.73	0.69	19.93	42.04	22.80	12.58	57.96
EUR	0.49	0.48	0.76	0.43	17.85	24.42	44.19	11.38	55.81
GBP	1.04	0.92	1.16	0.89	14.88	16.89	14.70	49.52	50.48
TO others	29.86	32.47	37.69	39.73	54.18	64.19	57.19	37.92	353.22
Inc. own	97.48	100.89	103.64	102.25	100.69	106.23	101.38	87.44	TCI
NET	− 2.52	0.89	3.64	2.25	0.69	6.23	1.38	− 12.56	44.15

CNY—Chinese Yuan, JPY—Japanese Yuan, EUR—Euro, GBP—Pound Sterling

returns on NFTs and conventional currencies is weak, the NFTs returns influence more than they are influenced by the returns of the conventional currencies. In summary, we provide empirical evidence that the NFTs returns are weakly connected with the returns of the conventional currency markets; therefore, NFTs are likely to act as hedging and diversifying tools against currency market risks.

Finally, the bottom row "NET" provides the net return spillovers. If the value of the net return spillovers is positive (negative), then the market is a net transmitter (receiver). As reported in Table 3, all NFTs, as well as EUR and JPY, are net transmitters of static return spillovers. We observe that only CNY and GBP are receivers of static return spillovers.

Table 4 presents the results of volatility spillovers between NFTs and conventional currencies. The total volatility spillovers index is 44.15%, which is slightly greater than the total return spillovers index (41.02%), implying that the volatility linkages are somewhat stronger compared with the connectedness of total returns. The rightmost column "FROM others" represents the total volatility spillovers from the system to each market. The results reveal that the conventional currencies receive relatively high volatility spillovers from the system (all above 50%), which is superior to those received by the NFTs (all below 40%). Moreover, analyzing the spillovers not from the entire system but from NFTs to conventional currencies reveals that the influence of NTFs on the currency market volatility is weak. Therefore, the shocks in NFTs are not expected to considerably affect the currency markets.

The row "TO others" indicates the volatility spillover from each market to the system. The results reveal that the system receives the highest volatility spillovers from JPY (64.19%), EUR (57.19%), and CNY (54.18%), whereas the lowest volatility effects are transmitted to the system from THETA (29.86%) and XTZ (32.47%). In addition, analyzing the spillovers not to the entire system but from conventional currencies to NFTs reveals that the influence of the conventional currencies on the NFTs market volatility is weak. This indicates that conventional currencies are not significant determinants of the NFTs market volatility. Moreover, comparing the two shadowed areas of Table 4, we conclude that although the interrelation of the NFTs and the volatility of conventional

currencies is weak, the influence of the volatility of NFTs is more than the influence of the volatility of the conventional currencies on them. Overall, we provide empirical evidence that the volatilities of NFTs are weakly connected with the volatilities of the conventional currency markets; therefore, NFTs are likely to act as hedging and diversifying tools against currency market risks. Hence, portfolio managers can increase benefits from diversification by adding NFT assets to their currency portfolios.

The bottom row "NET" indicates the net volatility emitters and recipients. Among the NFTs, ENJ (3.64%), MANA (2.25%), and XTZ (0.89) are the net volatility transmitters, while THETA (-2.52%) is a net volatility receiver. Regarding conventional currencies, JPY (6.23%), EUR (1.38%), and CNY (0.69%) are net transmitters of volatility spillovers, while GBP (− 12.56%) is a major net receiver of volatility effects.

Dynamic return and volatility spillovers

In this section, we investigate the dynamic connectedness between the system's variables, that is, NFTs and conventional currencies. Figure 3 depicts the time dynamics of the time-varying return and volatility connectedness between NFTs and conventional currencies. The overall return and volatility spillovers increased sharply from 25 to 47% and from 39 to 62%, respectively, by the end of the first quarter of 2020, coinciding with the outbreak of COVID-19, which triggered the meltdown of financial markets in March 2020 (Gubareva 2021). Regarding the volatility spillover, after its all-time highs in March 2020, it remained above the pre-COVID-19 levels for several months. Following a year-long decline, it reached its lowest level (25%) during the second quarter of 2021. Overall, our findings highlight that the pandemic significantly influenced interrelations in the NFTs and currency markets and significantly increased the volatility connectedness of the system.

Figure 4 illustrates the dynamic total spillovers of returns from each variable to the system. The plots depict that all variables in the system exhibit significant time-varying return transmissions to the system. Moreover, we notice that return spillovers from all NFTs to the system abruptly increased during the rapid expansion of the pandemic in March 2020, upsurging from below 30% to above 60%. Higher spillovers during the COVID-19 crisis are also observed in many studies (Mensi et al. 2022). However, dynamic spillovers from returns of currencies to the system decreased since the

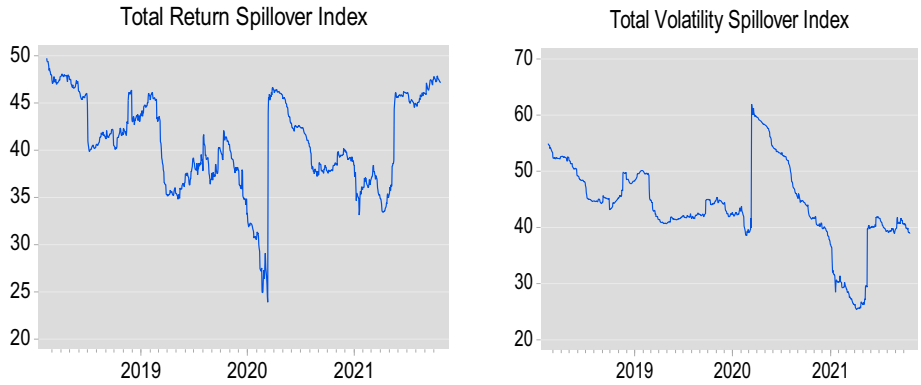

Fig. 3 Total return and volatility spillover indices (2018–2021)

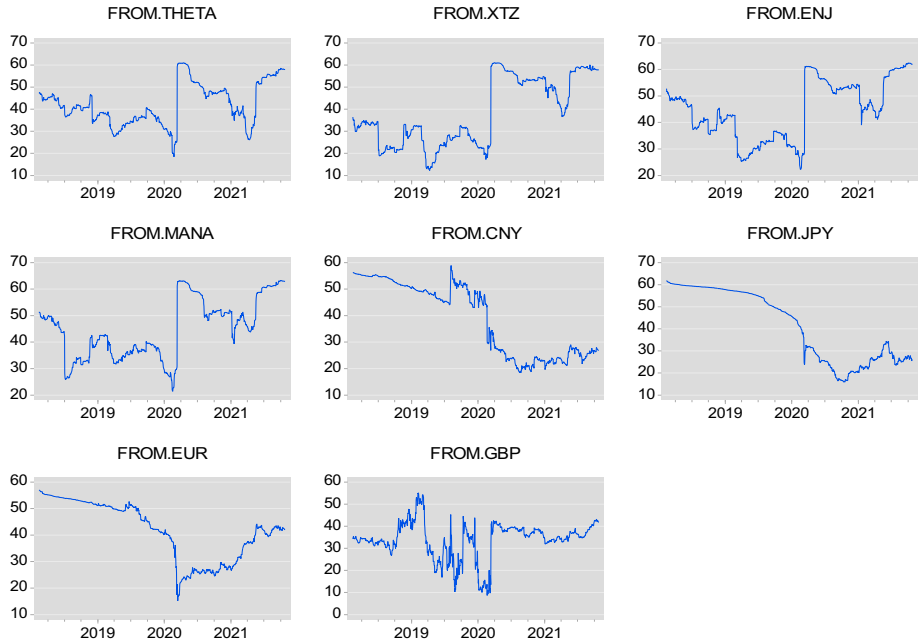

Fig. 4 Return spillover from each market to system

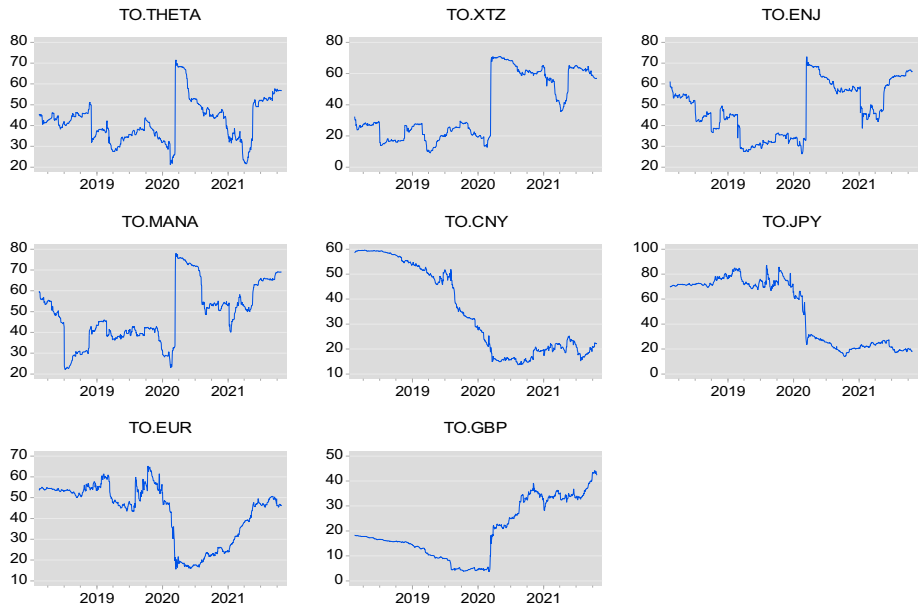

Fig. 5 Return spillover from system to each market

beginning of the sample period and reached their lowest levels, below 20%, during the early pandemic period in the first quarter of 2020.

Figure 5 depicts the time-varying return spillovers from the system to each market. The plots depict that the return spillovers from the system to the NFTs and the conventional currencies suffered pronounced variations over time. Additionally, dynamic return spillovers from the system to all NFT assets abruptly increased during the onset

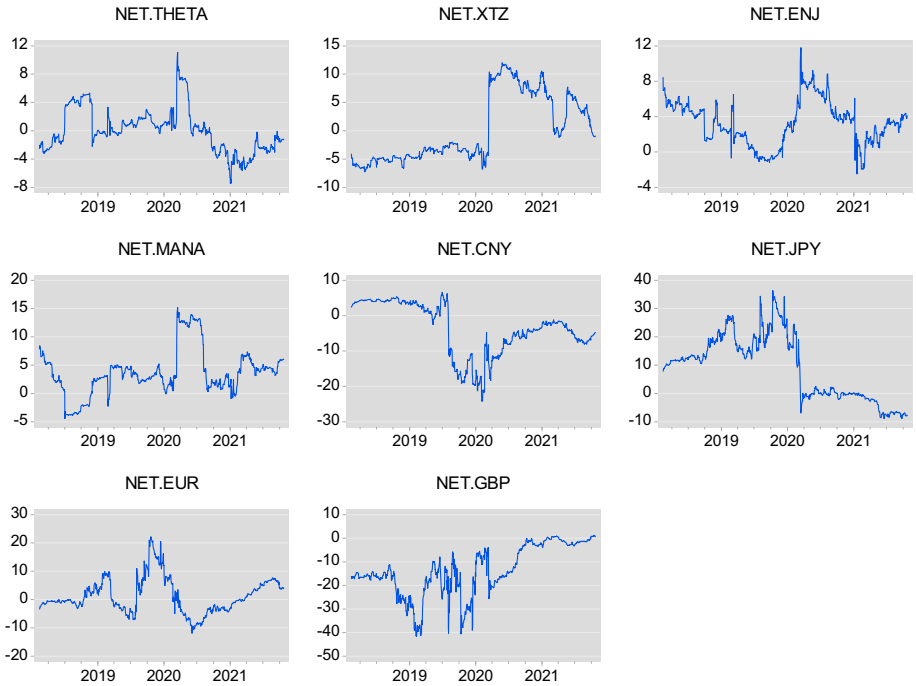

Fig. 6 Net return spillovers

of the COVID-19 pandemic. Regarding the return spillovers from the system to all currencies, the spillovers declined since the beginning of the sample period until the pandemic-triggered market meltdown in March 2020 and then continued on the so-called lateral trends, except for GBP, for which we observe a hike in the spillover received, which is similar to those observed for the NFTs.

Figure 6 illustrates the net return spillovers for the NFTs and conventional currencies. The plots depict that the net return spillovers vary over time in all considered markets. The plots also depict that all NFTs acted as net transmitters of return spillovers during the start of the COVID-19-triggered crisis and the rest of the first pandemic year. Then, in 2021, THETA became a clear net receiver. Among the conventional currencies, JPY had the greatest spillover transmission before the pandemic outbreak and lost its influence on the system afterward. Since the start of the COVID-19-triggered market meltdown in March 2020, all currencies acted as return spillover receivers; however, in 2021, EUR began to act as a net transmitter. This finding may be explained by the linkages between crypto-assets and the euro area banking sector, which have been limited so far, although market contacts indicate that there was growing interest in 2021, mainly via expanded portfolios or ancillary services associated with digital assets, including custody and trading services. Moreover, major payment networks have also stepped up their support of crypto-asset services, leveraging their retail networks and making crypto-assets more easily accessible to consumers and businesses. Some institutional investors (hedge funds, family offices, some nonfinancial firms, and asset managers) are now also investing in Bitcoin and crypto-assets.

Overall, all net return spillovers varied significantly during the first pandemic year of 2020, highlighting the important influence of the outbreak of the pandemic on the

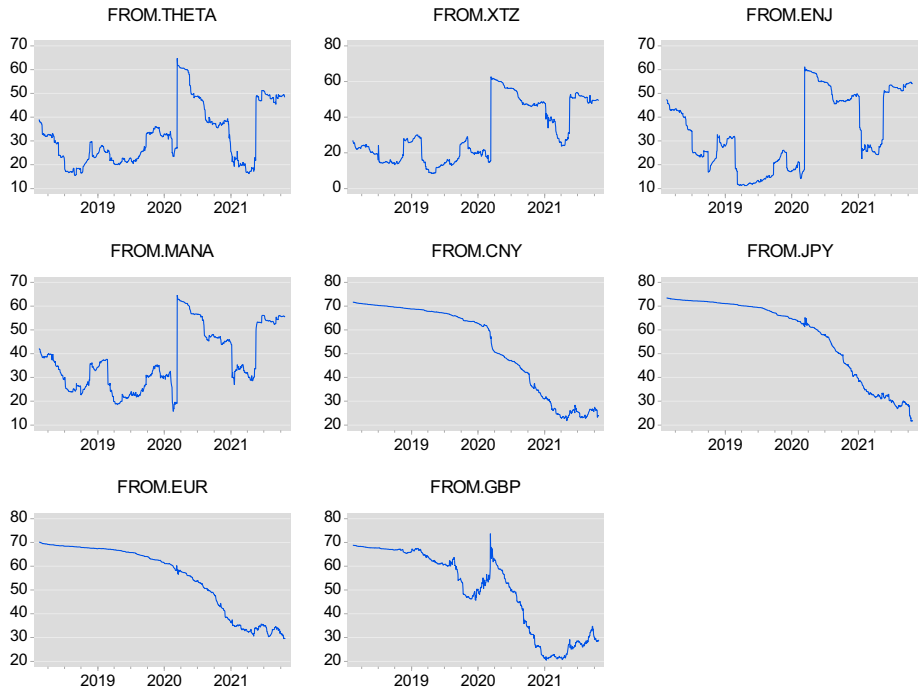

Fig. 7 Volatility spillover from each market to system

return-based connectedness within the system, comprising NFTs and conventional currencies.

Figure 7 illustrates the time-varying volatility spillovers from each market to the system. We notice that the volatility transmissions from each market to the system exhibit large variations over time. Moreover, volatility spillovers from NFTs to the system sharply increased, from about 20% to above 60%, during the pandemic onset in March 2020. Conversely, volatility spillovers from the currency markets to the system exhibited declining trends since the beginning of the sample period and accentuated their decline throughout the first year of the pandemic. It is worth mentioning that volatility spillovers from the currency markets registered their lowest levels, below 30%, in 2021. These findings highlight a strong impact of the COVID-19 crisis on NFTs and currency markets, which contrasts with the finding of Aharon and Demir (2021), who found that NFTs are mainly independent of shocks from other asset classes and that NFT assets absorbed risks during the COVID-19 crisis. The predominance of the volatility spillovers to the system from currency markets before the pandemic caused the preponderance of the volatility spillovers from NFTs during the COVID-19 period. This result indicates that the COVID-19 pandemic strengthened the integration of the NFTs into the international currency markets. This increase in the correlation between returns on crypto-assets and conventional currencies during and after the market crisis of March 2020, as well as during the December 2021 and May 2022 market sell-offs, casts doubt over their usefulness for portfolio diversification. This may suggest that, during periods of risk aversion across wider financial markets, the crypto-asset market becomes more closely tied to traditional risk assets. These findings are similar to results of (Sebastião and Godinho 2021). Conversely, the correlation with gold turned negative during a period of

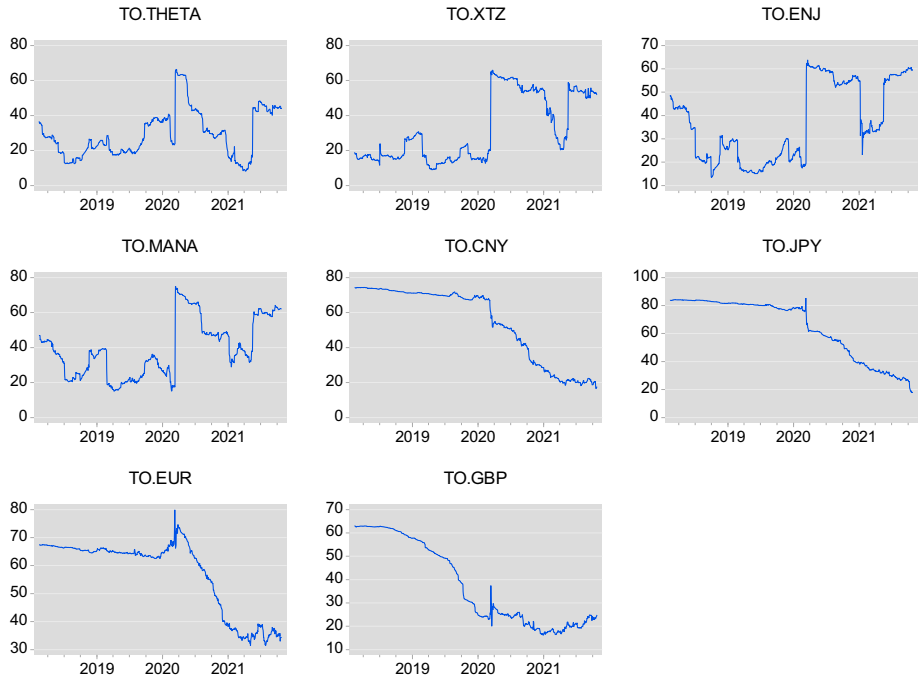

Fig. 8 Volatility spillover from system to each market

rising inflation expectations and geopolitical tensions, as demonstrated by Yousaf and Yarovaya (2022a, b).

We also analyzed the dynamic volatility spillovers from others, which indicate the amount of volatility spillovers transmitted from the system to each market. The dynamic volatility transmissions from the system to each market are depicted in Figure 8. The plots indicate that the magnitudes of volatility shocks received from the system vary over time and differ for each variable. The volatility spillovers from the system to the NFTs exhibit abrupt increases from about 20% to above 60%. These pronounced hikes coincided with the COVID-19-triggered market meltdown in March 2020. The volatility spillovers emitted from the system to the currency markets were mostly on the downtrend during the whole sample period. Still, we notice short-term oscillations in volatility spillovers during March for JPY, EUR, and GBP markets, which, however, do not cause any persistent change in the long-run decrease in the magnitudes of the volatility shocks received from the system.

Finally, we calculate the net dynamic volatility spillovers. The patterns of the net volatility transmission are depicted in Figure 9. We conclude from the plots that all markets switched between net receivers and net transmitters roles during the sample period, especially during the onset of the recent health crisis and the ongoing pandemic. We notice that XTZ and MANA assets mostly acted as net receivers of volatile spillovers in the pre-crisis period but turned into net transmitters since the onset of the pandemic. THETA predominantly acted as a net transmitter during the second half of 2019 and the first half of 2020 but turned to a net receiver of volatility spillovers since the second half of 2020, i.e., during the recovery from the COVID-19-triggered economic meltdown. Regarding the currency markets, the plots indicate that CNY and JPY, which acted as net

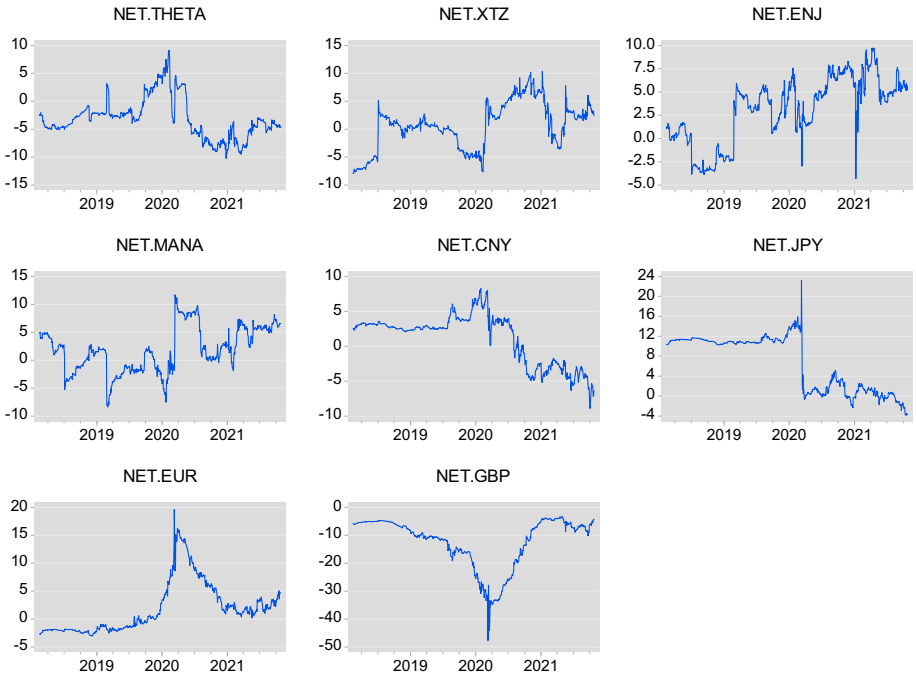

Fig. 9 Net volatility spillovers

transmitters of volatility spillovers before COVID-19, switched to net receivers. Regarding the Chinese currency market, the switching role from net emitter to net receiver of dynamic spillovers may be explained by the recent rapid development of NFTs in China. The Initiative to Prevent Relevant Financial Risks of NonFungible Tokens is the first government document with a compliance focus on NFTs. This not only provides the first official translation of NFT into Chinese but also affirms the use of the NFT idea in China and clearly distinguishes it from cryptocurrencies, which are forbidden. Additionally, it establishes NFT as a novel and distinctive use of blockchain technology and affirms that it has a specific value in advancing the growth of China's creative and cultural sectors. It also emphasizes that there may be hazards associated with speculating, money laundering, and other illicit financial activities while using NFTs. As digital collections are based on NFTs and the development is still at an early stage, with unclear value standards, the self-regulatory requirements mainly reiterate relevant requirements in the initiative and propose reasonable expectations[1].

Whereas EUR experienced opposite dynamics, GBP always remained a net receiver, although with the COVID-19-triggered switch of the increasing volatility shocks, absorption do diminishing one, clearly observed in March 2020. Our findings suggest that investors seeking to reduce volatility should regularly rebalance their portfolios, combining NFTs and conventional currencies, especially during periods of market turmoil.

Figure 10 presents the network diagrams for returns and volatilities connectedness between NFTs and conventional currencies. The returns connectedness diagram

[1] https://www.mondaq.com/china/fin-tech/1245566/nfts-in-china-

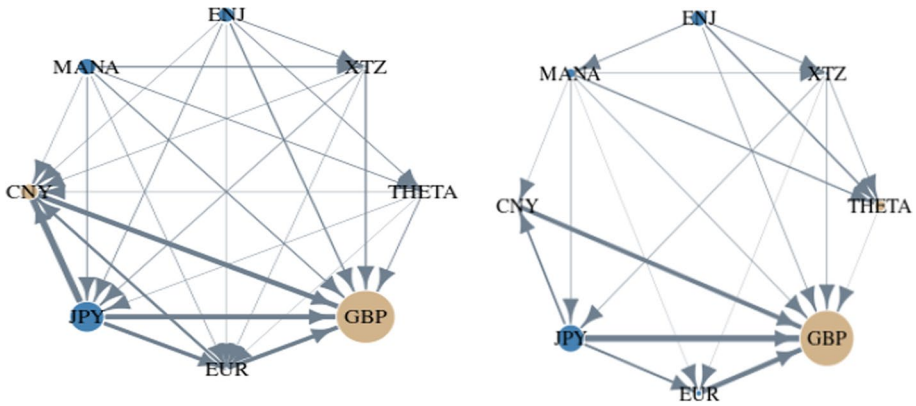

Fig. 10 Network connectedness diagrams

illustrates that shocks in NFTs returns significantly affected conventional currencies returns and that NFTs are net transmitters of return spillovers to currency markets. Therefore, we find that NFTs play the role of sources in the net pairwise return spillovers with currency markets, while conventional currencies act as net receivers of the pairwise return spillovers from NFTs. This conclusion is also corroborated by the comparison of the two shadowed areas in Table 3. Similarly, regarding volatility spillovers, the network volatility connectedness diagram also reveals that volatility shocks from NFTs significantly affect conventional currencies. In fact, NFTs transmit more volatility spillovers to conventional currency markets than they receive. This means that these relatively new digital assets influence the volatility of the conventional currency markets more than their volatility is influenced by the volatility shocks of the latter. This conclusion is also corroborated by the comparison of the two shadowed areas in Table 4. However, the net pairwise influence of NFTs on conventional currencies is more pronounced in the case of return spillovers than in the case of volatility spillovers.

Conclusion

This study investigates the connectedness as well as return and volatility spillovers in investment portfolios comprising NFTs and conventional currencies. We add to the incipient but rapidly growing research on this type of relatively new digital assets and their interrelations with traditional financial instruments, that is, conventional currencies. More specifically, we provide empirical evidence of attractive hedging attributes and diversification opportunities that NFTs exposure possess vis-à-vis the downside risks of the conventional currencies market. We apply the recently introduced TVP–VAR methodology, which substantially improves the traditional connectedness approach based on forecast error variance decomposition. The TVP–VAR model overcomes serious shortcomings of the traditional framework related to the arbitrarily chosen size of the rolling window, which can lead to very erratic or flattened parameters and a loss of valuable observations.

The results of this study reveal that the analyzed NFTs exhibit higher risk and higher returns compared with those of conventional currencies. Our static return spillover and volatility spillover analyses provide empirical evidence that the total connectedness between these two markets was weak during the whole sample period, implying that

linkages between NFTs and currencies markets are negligible and investors may increase diversification benefits by adding NFT assets to their multicurrency portfolios. Moreover, we find that NFTs play the role of sources in the net pairwise returns and volatility spillovers in currency markets, suggesting that the currency markets are not effective predictors of NFTs returns and volatilities. In addition, we document that NFTs' net pairwise influence on conventional currencies is more pronounced in the case of return spillovers than in the case of volatility. The results of the net spillovers reveal that all the NFTs, JPY, and EUR are net transmitters of return spillovers, whereas CNY and GBP are net receivers. Regarding volatility spillovers, the NFTs, except THETA, and the conventional currencies, except GBP, are net transmitters of volatility innovations.

We also observe that the total amount of return spillovers from (to) the system to (from) conventional currency markets is inferior to that of return spillovers from the system to the NFTs. However, for the volatility spillovers, we observe opposite patterns and report that currency markets receive (transmit) the highest volatility effects from (to) the system. Herein, we report the from/to-the-system-related findings but do not draw any conclusions from them. Moreover, an interrelation of a particular group of markets, i.e., NFTs and currencies, with the system should be interpreted cautiously to draw conclusions on the interactions between these groups of markets within the system, as strong endogenous effects in the NFTs and strong endogenous effects in the conventional currencies may disguise and dilute rather weak exogenous interactions between these groups of markets.

The dynamic connectedness exercise reveals that return and volatility spillovers vary over time, especially during periods of market turmoil. The volatility spillovers reached unprecedented highs in the first quarter of 2020, which coincided with the onset of the COVID-19 pandemic. Our results highlight that NFT–currency connectedness increases during a period of stress, suggesting that investors and portfolio managers should regularly rebalance their NFT–currency portfolio. Finally, the returns and volatility network diagrams depict that the shocks to returns and volatility of the NFTs affect currency markets more strongly than the NFTs themselves are affected by shocks to returns and volatilities of currency markets. Thus, NFT assets act as net emitters of return and volatility shocks to the currency markets. However, NFTs' net pairwise influence on conventional currencies is more pronounced in the case of return spillovers than in the case of volatility spillovers.

In summary, our study contributes to the literature by providing useful information about asset allocation, forecasting, diversification, and hedging opportunities. Our findings can be useful to investors and portfolio managers interested in NFTs to diversify their conventional multicurrency portfolios. Considering the small size of the NFT market with respect to the cryptocurrency market, serious long-term institutional investors may not use it (NFTs) for meaningful asset allocation strategy. However, retail investors can use NFTs to diversify their portfolios. For future studies, we recommend exploring the determinants of spillovers between NFTs and conventional cryptocurrencies during various events, such as the COVID-19 pandemic and the Russia–Ukraine war. Further, NFTs can be studied with other green/clean traditional markets and technology stocks to explore their diversification advantages.

Abbreviations

NFTs	Non-fungible tokens
XTZ	Tezos
ENJ	Enjin Coin
MANA	Decentraland
CNY	Chinese Yuan
JPY	Japanese Yen
EUR	Euro
GBP	Pound Sterling

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Author contributions
IY: Conceptualization, Data curation, Software, methodology, writing & reviewing; MY: writing & reviewing; MG: Investigation, validation; project administration; writing - original draft; writing - review & editing, funding, resources.

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Declarations

Competing interests
The authors declare that they have no competing interests.

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