Gülcan, N. ve Mumcu Küçükçaylı, F. (2024). "The Volatility Spillover in Metaverse Token Market: TVP-VAR Model Application", Eskişehir Osmangazi Üniversitesi İİBF Dergisi, 19(3), 906 – 922.
Doi: 10.17153/oguiibf.1399452

Başvuru: 02.12.2023 Kabul: 06.04.2024 *Araştırma Makalesi/Research Article*

The Volatility Spillover in Metaverse Token Market: TVP-VAR Model Application

Nazlıgül Gülcan[1]

Fatma Mumcu Küçükçaylı[2]

Metaverse Token Piyasasında Volatilite Yayılımı: TVP-VAR Modeli Uygulaması

Öz

Bu çalışmada, yatırımcılara yol göstermek amacıyla metaverse tokenler arasındaki volatilite yayılımı araştırılmıştır. Araştırmada Decentraland, StarLink, Axie Infinity, Radio Caca, The Sandbox, Internet Computer, My Neighbor Alice ve Enjin Coin'in 12.14.2021-10.22.2023 dönemine ait fiyat verileri Antonakakis vd. (2019) tarafından geliştirilen zamanla değişen parametreli vektör otoregresif (TVP-VAR) modeli ile analiz edilmiştir. Araştırma sonucunda Radio Caca ve Axie Infinity'nin sadece volatilite alan; My Neighbor Alice ve Enjin Coin'in sadece volatilite yayan; StarLink, Decentraland ve Internet Computer'ın ise hem volatilite alan hem de volatilite yayan metaverse tokenler olduğu belirlenmiştir.

Anahtar Kelimeler: Metaverse Token, Volatilite Yayılımı, TVP-VAR

JEL Kodları: G10, G17

The Volatility Spillover in Metaverse Token Market: TVP-VAR Model Application

Abstract

In this study, the volatility spillover between metaverse tokens is investigated to guide investors. In the research, price data of Decentraland, StarLink, Axie Infinity, Radio Caca, The Sandbox, Internet Computer, My Neighbor Alice and Enjin Coin, for the period 12.14.2021-10.22.2023 analyzes with the time-varying parameter vector autoregressive (TVP-VAR) model developed by Antonakakis et al. (2019). As a result of the research, it determines that Radio Caca and Axie Infinity only receive volatility; My Neighbor Alice and Enjin Coin only spread volatility; StarLink, Decentraland and Internet Computer are metaverse tokens that both receive and spread volatility.

Keywords: Metaverse Token, Volatility Spillover, TVP-VAR

JEL Codes: G10, G17

Araştırma ve Yayın Etiği Beyanı	Bu çalışma bilimsel araştırma ve yayın etiği kurallarına uygun olarak hazırlanmıştır.
Yazarların Makaleye Olan Katkıları	Çalışmanın tamamı iki yazar ile birlikte oluşturulmuştur.
Çıkar Beyanı	Yazarlar açısından ya da üçüncü taraflar açısından çalışmadan kaynaklı çıkar çatışması bulunmamaktadır.

[1] Assoc. Prof. Dr. Burdur Mehmet Akif Ersoy University, Bucak Business Administration Faculty, Business Administration Department, nazligulgulcan@mehmetakif.edu.tr

[2] Assist. Prof. Dr., Burdur Mehmet Akif Ersoy University, Ağlasun Vocational School, Finance-Banking and Insurance Department, fmumcu@mehmetakif.edu.tr

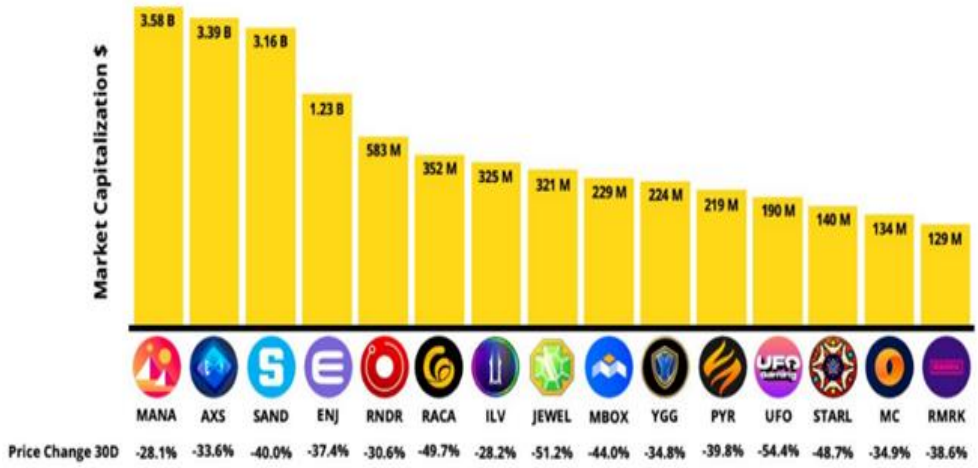
1. Introduction

Innovations in computer technologies have an important role in daily life by changing and enriching communication and social processes. Personal computers, the internet and mobile devices have been recorded as three major technological innovations for users. Recently, the fourth wave of computer innovation has developed through spatial, immersive technologies such as Virtual Reality (VR) and Augmented Reality (AR) (Mystakidis, 2022: 486). Virtual reality detaches the user from reality by involving her/him in virtual environment other than her/his current physical environment, thus creates the feeling of being in another environment for the user. Augmented reality is a system that combines real and virtual content, is interactive in real time and is recorded in three dimensions. Virtual reality creates a sense of presence in the virtual environment for the user while augmented reality provides the user with a feeling of presence in their real environment (Steffen et al., 2019: 687-690). Another concept between technological innovations is blockchain[3]-based decentralized technologies "new digitalization wave or Web 3.0" (Sert, 2019: 11-71). Web 3.0 cryptocurrency includes the concepts of Non-Fungible Token (NFT), Decentralized Autonomous Organization (DAO), Decentralized Finance (DeFi), and metaverse (Sert, 2022: 46).

A virtual universe with its own economies, trade and currencies has been developed with the combination of blockchain technologies and the gaming industry (Vidal-Tomás, 2022: 1). This virtual universe, based on augmented reality, virtual reality and blockchain technologies, is defined as 'Metaverse', is the center of attention today and the newest concept (Dwivedi et al., 2022: 2; Lee et.al., 2021: 3). Although the concept of "Metaverse" used by technology critics and academics is known as a new concept, it first appeared in Neal Stephenson's science fiction novel "Snow Crash" in 1992 (Dwivedi et al., 2022: 2). In the book, Neal Stephenson conceptualized the virtual world in which people interact with each other through avatars and named it 'Metaverse' (Ağırman and Barakalı, 2022: 331). The Metaverse concept, which was first mentioned years ago, came to the fore again when Mark Zuckerberg changed to "Meta" the name of the social media platform in 2021, and became very popular (Güler and Savaş, 2022: 293). Metaverse basically represents the third dimension added to the traditional two-dimensional internet. Metaverse allows to interact seamlessly in real and simulated environments to the user through avatars and holograms, and offers the opportunity to expand the physical world (Dwivedi et al., 2022: 2). Metaverse offers participants a virtual reality platform where they can produce and sell goods and services, make various applications and games, as well as create their own local cryptocurrencies for the participants (Akkus et al., 2022: 28). Metaverse tokens are a technological ecosystem that creates a world based on virtual reality by imitating the real world and allows individuals to create their own virtual world by enabling real-world transactions such as land and property exchange in the virtual world (Büberkökü, 2022: 383). Metaverse token market has been in high demand by investors, recently. The top 15 metaverse token rankings by market value as of March 10, 2022 are shown in Figure 1.

[3] Blockchain technology is a decentralized system that allows digital assets to be moved without the need for an agent.

Figure 1: Top 15 Metaverse Tokens by Market Value (March 10, 2022)



Source: CryptoDep, Top #Metaverse Tokens by Market Capitalization, March 10, 2022.

According to Figure 1, Decentraland (MANA) ranks first with 3.58 billion dollars, Axie Infinity (AXS) ranks second with 3.39 billion dollars, and The Sandbox (SAND) ranks third with 3.16 billion dollars. MANA defines as a virtual reality platform supported by the Ethereum blockchain and allows the user to create content and applications, earn experience and money. Axie Infinity describes as a blockchain-based trading and war game with partial player ownership, and provides its players the opportunity to collect, breed, fight and trade token-based creatures called "Axie". The Sandbox defines as a blockchain-based virtual world that offers digital assets the users and allows to buy and sell (Coinmarketcap). The rapid growth of the metaverse, which offers a digital ecosystem, has attracted the attention of the technology and finance sectors (Horky, 2023: 1). One of the most significant factors the interest is the economic expectations promised by the metaverse. "*According to Citibank, the Metaverse is projected to generate revenue of approximately $5 trillion to $8 trillion by 2030*" (Citi, 2022; Aysan et al., 2023: 2). It can be said that these expectations will also increase the demand for metaverse tokens, the digital assets used in the system.

Blockchain-based decentralized digital assets (such as NFTs, DeFi, and metaverse tokens) outside of cryptocurrencies are new research topics in the literatüre. These studies focus mostly on the relationship of NFT, DeFi and cryptocurrencies with each other or with other financial assets (Aharon and Demir, 2022; Akkus, Gursoy and Dogan, 2022; Akkus and Dogan, 2023; Alawadhi and Alshamali, 2022; Ante, 2021; Dowling, 2022; Karim et al., 2022; Pinto-Gutiérrez et al., 2022; Yousaf and Yarovaya, 2022). The literature on metaverse tokens is limited (Sonmezer and Çelik, 2022; Büberkökü, 2022; Vidal-Tomás, 2022; Akkus et al., 2022; Vidal-Tomás, 2023; Horky, 2023). The importance of examining the metaverse and digital assets in the literature is emphasized. Vidal-Tomás (2023) emphasized that it is necessary to focus on the long-term value of risk capital collected for metaverse projects, despite the bear market conditions. He reported that researchers should continue to analyze the characteristics of the metaverse market. Vidal-Tomás (2022) stated that portfolio managers can diversify own cryptocurrency portfolios with metaverse tokens. On the other hand, Horky (2023) stated that it is important to analysis the specific features of metaverse tokens for investment strategies

and risk management. With the expected future size of the metaverse and recommendations in the literature, it is considered important to study metaverse tokens. We believe that this study will contribute to both investors and the literature.

The metaverse token market, whose market values have rapidly increased, has attracted the attention of potential investors and portfolio managers because it offers an alternative investment instrument. It is an important process for investors and portfolio managers to manage optimum portfolio return and risk by choosing between alternative investment instruments in financial markets, and in this process, it is necessary to determine the volatility spillover between financial assets. The dictionary meaning of the concept of volatility is 'fluctuation'. In financial terms, volatility is "It is the expression of the variability in the price of the asset. High volatility is an indicator of increased uncertainty" (Dictionary of Terms of the Central Bank of the Republic of Turkey, 32). Volatility is the most important factor to understand the risk characteristic and market making, portfolio optimization, hedging and risk management of the financial asset (Şenol et al., 2022: 927). When the volatility spillover in financial markets is examined, it determines whether the information that has an impact on the volatility level of the financial asset has an impact on the volatility level of other financial assets. As a result of the important information, it allows investors and portfolio managers to make their investment strategies more effective (Büberkökü, 2021: 2). It is important to examine the volatility spillover between metaverse tokens as an alternative investment asset for digital asset investors. Volatility spillover information of digital assets known to be highly volatile will enable investors to develop strategies for optimal portfolio returns. It will provide investors with information for price forecasting, portfolio diversification and risk management. Therefore, the study examines the volatility spillover between metaverse tokens, which are popular between blockchain-based digital assets.

The contribution to the literature of the study is that it examines volatility spillovers between metaverse tokens comprehensively and with an advanced model. In the study, the volatility spillover between metaverse tokens are investigated with the time varying parameter vector autoregressive (TVP-VAR) model, which is proposed by Diebold and Yilmaz (2009, 2012, 2014) and developed by Antonakakis et al. (2019). "TVP-VAR's strengths lie in its adept handling of time-varying properties, easing stationarity assumptions, providing intuitive parameter interpretation, and offering a flexible depiction of evolving economic structures through a first-order random walk process" (Ali et al., 2024: 2).

The study consists of four parts. In the first part, the importance of metaverce tokens in financial markets and the volatility concept are explained. In the second part, empirical studies investigated the volatility spillover between metaverse tokens and other financial assets include. In the third part, the method applied in the analysis and the analysis findings are explained, and in the last part, the findings of the research generally are interpreted.

2. Literature Review

The studies in the literature examining volatility spillovers for digital assets are mostly focused on cryptocurrencies. Volatility spillovers are an important feature of the digital asset market. Therefore, volatility in the cryptocurrency market has been studied in various aspects and has a large place in the literature. Bouoiyour and Selmi (2015), Chaim and Laurini (2018), Kumar and Anandarao (2019), Akkuş and Çelik (2020), Gubadlı and Sarıkovanlık (2023) examined volatility spillovers in the cryptocurrency market. Dyhrberg (2016) and Baur et al. (2018) analyzed the volatility spillover of cryptocurrencies with other variables (financial asset capability). Bakas (2022) examined the determinants of volatility in the cryptocurrency market. Bouoiyour and Selmi (2015) analyzed Bitcoin price volatility and they find that Bitcoin volatility is more affected by negative shocks. Chaim and Laurini (2018) examined the dynamics of Bitcoin's daily returns and volatility. They reported that Bitcoin has very high unconditional volatility and sudden price fluctuations. Kumar and Anandarao (2019) examined the volatility spillover dynamics between the returns of four major cryptocurrencies. They reported that cryptocurrency markets exhibit herd behavior. Akkuş and Çelik (2020) examined Bitcoin volatility with symmetric and asymmetric models. They found that the cryptocurrency market is not efficient. Gubadli and Sarıkovanlık (2023) examined the volatility structure of six leading cryptocurrencies. They reported that cryptocurrencies have a dense volatility clustering. Dyhrberg (2016) examined the similarities of Bitcoin with gold and US Dollar and found that Bitcoin shows similarities with gold and US Dollar. Baur et al. (2018) found different results. They found that Bitcoin has significantly different return, volatility and correlation characteristics than gold and US Dollar. Bakas (2022) examined the determinants of volatility in the Bitcoin market. He stated that the determinants are Google trends, total circulation, consumer confidence and the S&P500 Index.

Assets (NFT, DeFi ve metaverse) developed excluding blockchain-based decentralized technology asset crypto money are new research topics for the literature. These new assets have enabled the development of the cryptocurrency market (Yousaf and Yarovaya, 2022; Akkus et al., 2022; Akkus and Dogan, 2023). In the literature, the volatility spillover of cryptocurrencies, NFT and DeFi assets and relationship with each other or different financial assets have been investigated (Aharon and Demir, 2022; Akkus, Gursoy and Dogan, 2022; Akkus and Dogan, 2023; Alawadhi and Alshamali, 2022; Ante, 2021; Dowling, 2022; Karim et al., 2022; Pinto-Gutiérrez et al., 2022; Yousaf and Yarovaya, 2022). However, the number of studies on volatility spillover in metaverse coins and relationship with other assets is quite limited. Vidal-Tomás (2022) reported that metaverse coins are not connected to the cryptocurrency market. The study suggested that metaverse coins can be used in cryptocurrency portfolio diversification.

The relationship between cryptocurrencies and non-fungible token (NFT) examined by Ante (2021). Ante (2021) investigated between non-fungible token (NFT) market and cryptocurrency market assets. In the study, the daily data of NFT sales, users and Bitcoin and Ethereum for the period 01.01.2018-05.16.2021 were analyzed. In the study which the short-term Granger causality test was applied, it found that Bitcoin and Ethereum prices affect the NFT markets. Dowling (2022) investigated the volatility spillover between cryptocurrency market assets and NFTs. In the study, weekly data of Decentraland, CryptoPunk, Axie Infinity, Cometh, Bitcoin and Ethereum for the period March 2019-March 2021 were analyzed. Diebold and Yilmaz's (2012) the volatility spillover model indicated that there is a low volatility spillover between

cryptocurrencies and NFTs, and NFTs are low volatility spillover between themselves. Wavelet coherence analysis showed that Ethereum and Decentraland are co-movement. Alawadhi and Alshamali (2022), Karim et al. (2022), Akkus and Dogan (2023) investigated the volatility spillover between cryptocurrency, NFT and DeFi. Alawadhi and Alshamali (2022) investigated the relationship and volatility spillover between NFT, DeFi and cryptocurrency market assets. In the study, Bored Ape Yacht Club, The Sandbox, CryptoPunks, Art Blocks and Decentraland as NFTs; Cometh as DeFi; Bitcoin ve Ethereum as cryptocurrency market assets included, and daily data for the period 01.15.2021-12.06.2021 were analyzed. According to Diebold and Yilmaz's (2012) the volatility spillover model, it determined that the volatility spillover between themselves of non-traditional financial assets, and between DeFi and cryptocurrency market assets is limited. Karim et al.'s (2021) the quantile connectedness approach and Han et al.'s (2016) the cross-quantilogram model, it found that the volatility spillover of positive DeFi and cryptocurrency market assets exceeds the volatility spillover of negative NFT. Karim et al. (2022) investigated the volatility spillover between NFT, DeFi and cryptocurrency market assets. In the study, daily data of Theta, Tezos, Enjin Coin, Decentraland ve Digibyte, Chainlink, Maker, Basic Attention Coin, Synthetix, Bancor, Bitcoin, Ethereum, Binance Coin, Cardano and Tether for the period 03.15.2018-10.24.2021 were analyzed. GARCH, quantile VAR and Diebold and Yilmaz (2012) the volatility spillover model stated that there is strong volatility spillover between blockchain markets in mean, extremely low and extremely high volatility conditions, and NFTs have better diversification potential than other financial assets. Akkus and Doğan (2023), investigated the dynamic connectedness relationship between the cryptocurrency market, NFT and DeFi assets. In the study, Bitcoin and Ethereum as cryptocurrency market assets; Tezos and The Sandbox as NFTs; Chainlik and Uniswap as DeFis included, and daily data for the period 09.18.2020-11.17.2022 were analyzed by TVP-VAR model. As a result of the analysis, it stated that Ethereum and Chainlik spread volatility to other cryptocurrency market assets, and the volatility spillover between NFTs are less than other crypto assets.

Studies examining the relationship of blockchain technology assets with other assets are Aharon and Demir (2022), Akkus, Gursoy and Dogan (2022), Pinto-Gutiérrez et al. (2022) and Yousaf and Yarovaya (2022). Aharon and Demir (2022) investigated the connectedness between NFT, Ethereum and other financial market asset returns during the Covid 19 period. In the study, daily data of MSCI World Index, Bond Index Exchange Traded Fund, US Dollar Index, gold and crude oil for the period 01.01.2018-06.30.2021 were analyzed. According to the TVP-VAR model prediction, it found that the connectedness between the returns of financial assets increase during the Covid 19 period; NFT, gold and the US Dollar Index exhibit similar characteristics in risk absorption, and there is weak interaction between NFTs and other financial assets. Pinto-Gutiérrez et al. (2022) investigated the determinants of interest in NFT. In the study, weekly data of NFT Google search activity, Bitcoin and Ethereum, VIX, gold and S&P 500 returns for the period 12.01.2017-07.30.2021 were analyzed. Finally, VAR and Granger causality test revealed that the previous week's Bitcoin returns increase investors' interest in NFT. Wavelet coherence analysis found that increases in Bitcoin and Ethereum returns make NFT attractive. Yousaf and Yarovaya (2022) investigated the transfer of return and volatility between NFT, DeFi and other assets. In the study, daily price data of Theta Network, Tezos, Enjin Coin, Decentraland and DigiByte, Chainlink, Maker, Basic Attention Token and Synthetix, WTI oil, gold, Bitcoin and S&P 500 for the period 03.05.2018-01.07.2021 were analyzed by TVP-VAR and VAR-BEKK-GARCH models. It presented that NFT, most of Defi assets and Bitcoin are spreader of return and volatility, and gold and WTI oil are receiver of return and volatility.

Akkus, Gursoy and Dogan (2022) investigated the volatility spillover between the NFT Investment Index and the Global Technology Index (XTEC). In the study, daily data for the period 04. 19.2021-04.22.2022 were analyzed by DCC-GARCH model. As a result of the analysis, it determined that the 1% shock in XTEC increases the NFT Investment Index volatility by 0.24%, the 1% shock in the NFT Investment Index increases XTEC volatility 1.86%.

The research subject of the study, metaverse coins, is a new concept and include in a limited number of studies in the literature. Sonmezer and Çelik (2022) investigated the relationship between cryptocurrencies and metaverse coins with return and transaction volumes. The daily price data of Decentraland, Enjin Coin, Theta and Axis Infinity, Bitcoin and Ethereum for the period of 27.12.2020-27.01.2022 were analyzed by multiple regression analysis. It determined that Decentraland returns are effective on Enjin Coin returns, Enjin Coin returns are a positive effect on the returns of Decentraland, Theta, Axis Infinity and Ethereum, Enjin Coin's transaction volume is a negative effect on its returns, and other token returns and Bitcoin transaction volume are effective for the explanatory of Theta. Büberkökü (2022) investigated the portfolio management and hedging situations of metaverse coins (Axie Infinity, Decentraland, and The Sandbox). In the study, daily data for the period 11.04.2020-01.20.2022 were analyzed. Firstly, according to the AR(p)-GARCH(1,1), AR(p)-GJR-GARCH(1,1) and AR(p)-EWMA model prediction applied for market risk analysis, the downside market risk has values range from 18.1% to -24.6% for Axie Infinity, -16.5% to -20.1% for Decentraland, -22.1% to -25.7% for The Sandbox. Secondly, according to the AR(p)-Scalar BEKK, AR(p)-DCC-GARCH(1,1) and AR(1)-CCC-GARCH(1,1) model applied for portfolio management analysis, the optimal portfolio weights of Axie Infinity/Decentraland, Axie Infinity/The Sandbox and Decentraland/The Sandbox are 28.96%/71.04%, 37.01%/62.99% and 66.30%/33.70%, respectively. Finally, it revealed that to hedge long positions in Axie Infinity and Decentraland, it is necessary to take short positions in The Sandbox; to hedge long positions in The Sandbox, it is necessary to take short positions in Decentraland. In the literature, Vidal-Tomás (2022, 2023) provides the most comprehensive analysis and direction on the metaverse market. Vidal-Tomás (2022) investigated the performance and dynamics of NFTs, play-to-earn and metaverse tokens. In the study, daily price data of 174 token for the period 28.10.2017-31.10.2021 were analyzed by the robustness model. According to the results of the study, it determined that metaverse tokens and play-to-earn coins are positively related in the long term on mean, and these assets are not affiliated with crypto tokens. He reported that portfolio managers can diversify their cryptocurrency portfolios with metaverse tokens. Vidal-Tomás (2023) analyzed 88 metaverse and play-to-earn tokens during the period 10.28.2017-08.01.2022. In the study, he examined the economic development, the emergence of bubbles and the performance of metaverse tokens. He reported that metaverse tokens have higher volatility compared to traditional alternatives. He also found that metaverse tokens exhibit explosive behavior.

3. Analysis

3.1. Methodology

In the study, the volatility spillover between metaverse tokens are investigated with the time varying parameter vector autoregressive (TVP-VAR) model, which is proposed by Diebold and Yilmaz (2009, 2012, 2014) and developed by Antonakakis et al. (2019). TVP-VAR model is a method of both static and dynamic time series network analysis that reveals the connections in a given network and internally models the change in parameters. In the model, outlier sensitivity is eliminated by using the Kalman filter and the sliding window length is not chosen randomly. In addition, it provides effective results in small data sets as it does not cause data loss problems.

The general version of the TVP-VAR model is as follows:

$$y_t = A_t z_{t-1} + \epsilon_t \qquad \epsilon_t|\Omega_{t-1} \sim N(0, \Sigma_t) \tag{1}$$

$$vec(A_t) = vec(A_{t-1}) + \xi_t \qquad \xi_t \sim |\Omega_{t-1} N(0, \Xi_t) \tag{2}$$

$$z_{t-1} = \begin{pmatrix} y_{t-1} \\ y_{t-2} \\ \vdots \\ y_{t-p} \end{pmatrix} \qquad A_t' = \begin{pmatrix} A_{1t} \\ A_{2t} \\ \dots \\ A_{pt} \end{pmatrix} \tag{3}$$

In the equations, it is stated that y_t is the *mx1* vector, A_t and A_{it} are the mxmp vector, z_{t-1} is the *mpx1* vector, Ω_{t-1} is the information up to *t-1*, ϵ_t is the *mx1* vector, ξ_t is the m^2px1 dimensional vector, Σ_t and Ξ_t are the *mxm* and m^2pxm^2p dimensional vectors, respectively, and $vec(A_t)$ is m^2px1 dimensional vector of A_t. In the study of Diebold and Yilmaz (2014), generalized impulse response functions (GIRF) Ψ_{ijt}^{g} and generalized estimation error variance decompositions (GFEVD) $\tilde{\phi}_{ijt}^{g}(J)$ were used to estimate the generalized connectedness procedure. In the TVP-VAR model, it is converted into a vector moving average (VMA) representation based on the Wold decomposition theorem to calculate GIRF and GFEVD. VMA notation is expressed as follows:

$$\begin{aligned} y_t &= J'(M_t(z_{t-2} + \eta_{t-1}) + \eta_t) \\ &= J'(M_t(M_t(z_{t-3} + \eta_{t-2}) + \eta_{t-1}) + \eta_t \\ &\vdots \\ &= J'(M_t^{k-1} z_{t-k-1} + \textstyle\sum_{j=0}^{k} M_t^j \eta_{t-j} \end{aligned} \tag{4}$$

$$M_t = \begin{pmatrix} A_t \\ I_{m(p-1)} \quad 0_{m(p-1)xm} \end{pmatrix} \qquad \eta_t = \begin{pmatrix} \epsilon_t \\ 0 \\ \vdots \\ 0 \end{pmatrix} = J\epsilon_t \qquad J = \begin{pmatrix} I \\ 0 \\ \vdots \\ 0 \end{pmatrix} \tag{5}$$

GIRF Ψ_{ijt}^{g}, expresses the reactions of all variables *j* following a shock to variable *i*. Additionally, in the equations, M_t is the *mpxmp* dimensional matrix, J is the *mpxm* dimensional matrix and η_t is the *mpx1* dimensional vector. GFEVD, which indicates the bidirectional connectedness from variable *j* to variable *i*, and evaluates the effect of variable *j* on variable *i* in terms of estimation error variance, calculated as follows:

$$\phi_{ij,t}^{g}(J) = \frac{S_{ii,t}^{-1} \Sigma_{t=1}^{j-1} (\iota_i' A_t S_t \iota_j)^2}{\Sigma_{j=1}^{N} \Sigma_{t=1}^{j-1} (\iota_i A_t S_t A_t' \iota_i)} \qquad \tilde{\phi}_{ij,t}^{g}(J) = \frac{\phi_{ij,t}^{g}(J)}{\sum_{j=1}^{N} \phi_{ij,t,}^{g}(J)} \tag{6}$$

In the equations, ι_i is a zero vector with integrity at position *i*, $\Sigma_{i,j=1}^{N}\tilde{\phi}_{ijt}^{N}(J) = N$ and $\Sigma_{j=1}^{N}\tilde{\phi}_{ijt}^{N}(J) = 1$.

The total connectedness index (TCI), which expresses how a shock in one variable spreads to other variables, is calculated as follows:

$$C_t^g(J) = \frac{\Sigma_{i,j=1,i\neq j}^{N}\tilde{\phi}_{ijt}^{g}(J)}{\sum_{i,j=1}^{N}\tilde{\phi}_{ijt}^{g}(J)} \quad (7)$$

Total directional connectedness, which expresses how variable *i* spreads its shock to all other variables *j*, is calculated as follows:

$$C_{i\rightarrow jt}^{g}(J) = \sum_{j=1,i\neq j}^{N}\tilde{\phi}_{jit}^{g}(J) \quad (8)$$

The total directional connectedness from others, which indicates that variable *i* receives from all other variables *j*, is calculated as follows:

$$C_{i\leftarrow jt}^{g}(J) = \sum_{j=1,i\neq j}^{N}\tilde{\phi}_{ijt}^{g}(J) \quad (9)$$

The net total directional connectedness, which indicates the effect of variable *i* on the analyzed network, is calculated as follows:

$$C_{it}^{g} = C_{i\rightarrow jt}^{g}(J) - C_{i\leftarrow jt}^{g}(J) \quad (10)$$

According to the results, if C_{it}^{g} is positive, it means that the variable *i* affects more than the network itself; if C_{it}^{g} is negative, it means that the variable *i* is driven by the network.

If the net total directional connectedness is evaluated in even more detail;

$$\mathrm{NPDC_{ij}(H)} = \widetilde{\emptyset}_{\mathrm{jit}}(\mathrm{H}) - \widetilde{\emptyset}_{\mathrm{ijt}}(\mathrm{H}) \quad (11)$$

$\mathrm{NPDC_{ij}(H)}$>0 ($\mathrm{NPDC_{ij}(H)}$>0) indicates that variable *i* covers variable *j*.

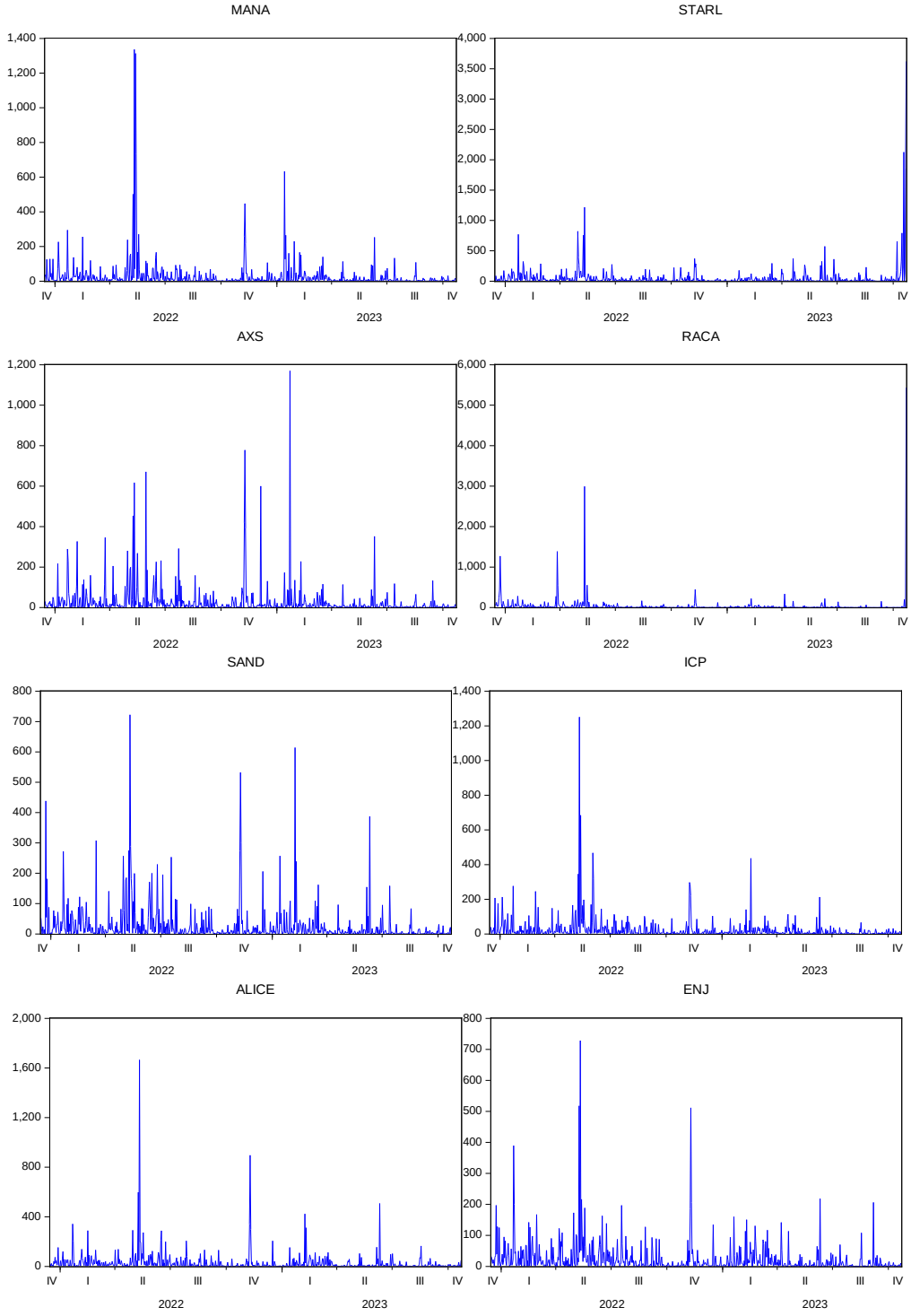
3.2. Data and Findings

In the study, the volatility spillover between metaverse tokens is investigated. In the research, Decentraland (MANA), StarLink (STARL), Axie Infinity (AXS), Radio Caca (RACA), The Sandbox (SAND), Internet Computer (ICP), My Neighbor Alice (ALICE) and Enjin Coin (ENJ) as metaverse tokens, which have the highest transaction volume are analyzed[4]. Daily price data in US Dollar for the period 12.14.2021-10.22.2023 include. The reason why this period is taken into consideration is because it is a period in which all metaverse tokens are traded simultaneously. These data are obtained from the 'tr.investing.com' data terminal. The return series of the metaverse tokens are calculated with the formula $ln(P\mathrm{t}/\mathrm{Pt}\text{-}1)*100$ and volatility series are created by the squares of the return series.

Time path graphs of the metaverse token series included in the research are shown in Figure 2.

[4] MANA has 45,39M, STARL has 4.613,59B, AXS has 2,45M, RACA has 76,84B, SAND has 21,93M, ICP has 1,42M, ALICE has 6,72M and ENJ has 5,37M transaction volume.

Figure 2: Time Path Graphs



According to Figure 2, it is seen that the metaverse token series exhibit a similar trend in all periods, also there is an intense increase in volatility in the second quarter of 2022, a decrease in volatility immediately afterwards. It is thought that the decrease in volatility may be caused by events such as the sudden decline in Bitcoin in May 2022 and the stopping of the Terra blockchain (since metaverse tokens are evaluated together with crypto assets).

Descriptive statistics of the metaverse token series are given in Table 1.

Table 1: Descriptive Statistics

	MANA	**STARL**	**AXS**	**RACA**	**SAND**	**ICP**	**ALICE**	**ENJ**
Mean	28.423	55.336	30.292	40.611	27.247	25.566	30.167	24.676
Variance	8528.358	40197.86	7211.185	64577.972	4161.051	5166.607	8231.793	2981.531
Skewness	9.868*	11.751*	7.155*	16.923*	5.503*	9.834*	11.096*	6.526*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Kurtosis	122.126*	174.976*	68.858*	326.836*	40.687*	138.824*	170.838*	62.277*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Jarque-Bera	431707*	879221*	139524*	3045583*	50112.6*	554544*	837168*	114211*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ERS	-8.012*	2.334**	-9.685*	-4.168*	-7.599*	-7.586*	-9.443*	-8.468*
	(0.000)	(0.020)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Q(10)	218.183*	145.262*	29.777*	4.200	79.744*	119.576*	69.041*	98.864*
	(0.000)	(0.000)	(0.000)	(0.633)	(0.000)	(0.000)	(0.000)	(0.000)
Q2(10)	195.669*	76.771*	3.285	0.003	24.377*	65.165*	10.24***	80.044*
	(0.000)	(0.000)	(0.778)	(1.000)	(0.000)	(0.000)	(0.062)	(0.000)

Note: *, ** and *** indicates 1%, 5% and 10% significance level. The values in parentheses are probability values.

According to Table 1, it is seen that StarLink has the highest mean, Enjin Coin has the lowest mean, and Radio Caca has the highest volatility, Enjin Coin has the lowest volatility. It determined that all series are positive and right-skewed with the skewness values, and are a sharper distribution, moving away from the normal distribution with the kurtosis values. The Jarque-Bera test statistic confirms that not all series exhibit normal distribution. Elliot, Rothenberg and Stock (1996) unit root test indicated that all series is stationary. It is stated that all series except Radio Caca with the Ljung Box Q test statistic and except Axie Infinity and Radio Caca with the Ljung Box Q2 test statistic, are related to their previous values, in other words, exhibit autocorrelation.

The volatility spillover between metaverse token series is investigated by TVP-VAR model developed by Antonakakis et al. (2019). The average dynamic connectedness results of metaverse token series predicted by the TVP-VAR(2) model, are given in Table 2.

Table 2: Averaged Dynamic Connectedness Results

	MANA	STARL	AXS	RACA	SAND	ICP	ALICE	ENJ	FROM
MANA	18.37	9.50	7.03	8.28	11.92	11.15	17.13	16.62	81.63
STARL	9.68	30.09	7.48	6.51	9.82	9.68	12.83	13.92	69.91
AXS	8.87	7.01	35.40	4.26	11.32	7.14	12.55	13.45	64.60
RACA	8.93	9.58	4.54	26.80	9.93	11.81	14.76	13.64	73.20
SAND	12.79	7.24	8.25	7.50	23.02	8.46	15.71	17.03	76.98
ICP	11.98	11.55	6.65	9.41	8.69	20.47	15.40	15.84	79.53
ALICE	11.69	9.86	8.12	9.56	12.38	10.80	20.71	16.88	79.29
ENJ	12.38	8.85	8.69	7.55	13.81	10.00	15.81	22.90	77.10
TO	76.34	63.60	50.76	53.06	77.87	69.05	104.19	107.37	602.24
Inc. Own	94.71	93.69	86.16	79.86	100.89	89.52	124.90	130.27	cTCI/TCI
NET	-5.29	-6.31	-13.8	-20.14	0.89	-10.4	24.90	30.27	86.03
NPT	5.00	2.00	2.00	0.00	4.00	2.00	6.00	7.00	75.28

Note: cTCI and TCI indicete dynamic conditional and static total connectedness index respectively. Inc. Own stands for the connectedness including the own variable.

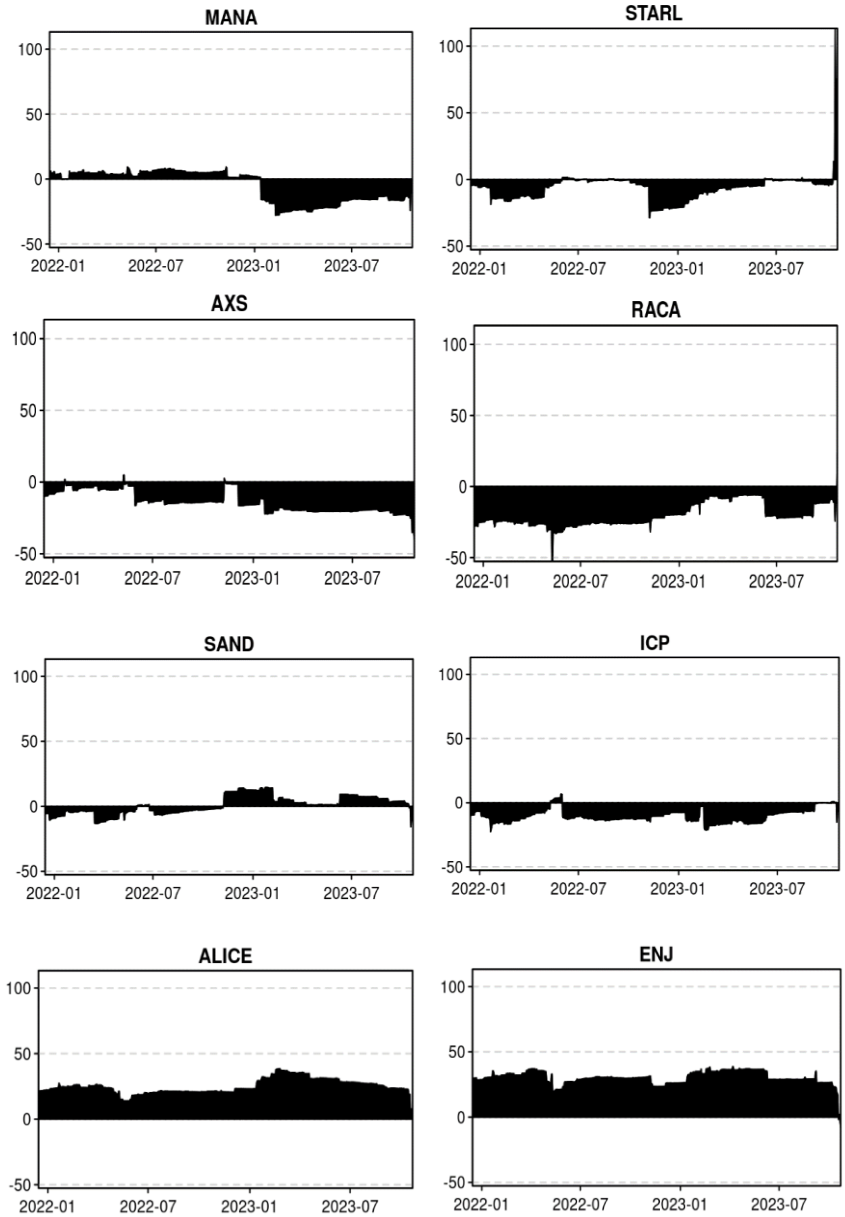
According to Table 2, it is determined that 18.37% of the volatility change in Decentraland, 30.09% of the volatility change StarLink, 35.40% of the volatility change Axie Infinity, 26.80% of the volatility change Radio Caca, 23.02% of the volatility change The Sandbox, 20.47% of the volatility change Internet Computer, 20.71% of the volatility change My Neighbor Alice and 22.90% of the volatility change Enjin Coin are due to themselves, the rest are from other metaverse tokens. In addition, it is observed that Decentraland (5.29%), StarLink (6.31%), Axie Infinity (13.8%), Radio Caca (20.14%) and Internet Computer (10.4%) receive a net volatility spillover; The Sandbox (0.89%), My Neighbor Alice (24.90%) and Enjin Coin (30.27%) spread a net volatility spillover. Generally, the results showed that metaverse tokens are affect by each other, and a large part of the the changes in the volatility of metaverse tokens are caused by them. Additionally, dynamic conditional (cTCI) and static (TCI) total connectedness index are observed to be highest between metaverse tokens valued at 86.03 and 75.28 respectively.

The dynamic total connectedness graph of metaverse token series is given in Figure 3.

Figure 3: Dynamic Total Connectedness

According to Figure 3, it is seen that the dynamic connectedness between metaverse token series increases in some periods and decreases in other periods. In order to see these trends in more detail, net total directional connectedness graphs of metaverse token series are given in Figure 3.

Figure 4: Net Total Directional Connectedness

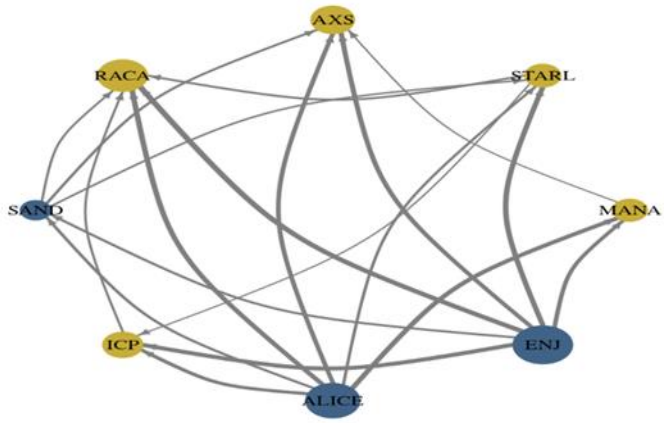


According to Figure 4, Radio Caca only receives volatility (have values below zero point), My Neighbor Alice is only spreads volatility (have values above zero point). In addition, it is

determined that StarLink, Axie Infinity and Internet Computer receive mostly volatility except for a few short periods; Decentraland, The Sandbox and Enjin Coin spread volatility intensely in periods.

The volatility spillover network plot graph of metaverse token series is given in Figure 5.

Figure 5: Network Plot



According to Figure 5, it is seen that Radio Caca and Axie Infinity only receive volatility, My Neighbor Alice and Enjin Coin only spread volatility, StarLink, Decentraland and Internet Computer are both receive and spread volatility. According to the size of the point, it is determined that Radio Caca receives the most volatility, followed by Axie Infinity, Internet Computer, StarLink and Decentraland, respectively. In addition, My Neighbor Alice spreads the most volatility, followed by Enjin Coin and The Sandbox, respectively.

4. Conclusion

It is an important process for investors and portfolio managers to manage optimum portfolio return and risk by choosing between alternative investment instruments in financial markets. Cryptocurrencies and digital assets used in the metaverse market, whose market size is increasing day by day, are in high demand by investors today and are used in portfolio diversification as new investment instruments. The volatility spillover between metaverse tokens is a matter of curiosity for investors, considering the estimated future size of the metaverse market. In the study is investigated the volatility spillover between metaverse tokens, for guider the portfolio creation processes of individual and institutional investors.

In the research, Decentraland, StarLink, Axie Infinity, Radio Caca, The Sandbox, Internet Computer, My Neighbor Alice and Enjin Coin as metaverse tokens, which have the highest market value and transaction volume, are analyzed. Daily price data in US Dollar for the period 12.14.2021-10.22.2023 include. In the study, the time-varying parameter vector autoregressive (TVP-VAR) model developed by Antonakakis et al. (2019), is applied. It is determined that Radio Caca and Axie Infinity only receive volatility, My Neighbor Alice and Enjin Coin only spread volatility, StarLink, Decentraland and Internet Computer are both receive and spread volatility. Radio Caca receives the most volatility, followed by Axie Infinity, Internet Computer, StarLink and Decentraland, respectively. In addition, My Neighbor Alice spreads the most volatility, followed by Enjin Coin and The Sandbox, respectively. The results obtained from the study are

similar to those published in the literature by Akkuş and Doğan (2023), Büberkökü (2022), Dowling (2022), Karim et al. (2022), Sonmezer and Çelik (2022) and Yousaf and Yarovaya (2022). The results show that Radio Caca and Axie Infinity are only affected by other metaverse token shocks, thus exposed to risk; My Neighbor Alice and Enjin Coin only affects other metaverse tokens, in other words, they act as risk transmitters. In particular, Radio Caca is the metaverse token that spreads volatility the most; Enjin Coin is the metaverse token that takes volatility the most. The findings from the study have some important policy implications. In August 2021, Poly Network was exploited for $611 million, Axie Infinity losed the highest volume as market efficiency declined, on November 30, 2021, and on November 30, 2021, the most expensive virtual land was sold for $4.3 million in The Sandbox; the Russia-Ukraine war broke out in February 2022, Andre Cronje left from DeFi in March and joined to Fantom again in November, with the collapse of FTX in the fourth quarter, the DeFimarket lost 24% value. In 2023 witnessed the introduction of Bitcoin Ordinals and the return of Solana (CoinCecko, 2021-2023 Annual Cyrpto Industry Reports). As can be seen, there are events arising from both the own dynamics and ecosystems of assets based on blockchain technology. Based on these events, those who have the potential to invest in metaverse tokens should follow the developments in the markets in order to protect their savings in case of uncertainty, and should consider only one of metaverse tokens included in the research in order to minimize portfolio risks. Potential investors, who want to invest in Radio Caca, Axie Infinity and StarLink should follow the price movements of My Neighbor Alice, Enjin Coin and The Sandbox, and who want to invest in Decentraland and Internet Computer should follow the price movements of My Neighbor Alice and Enjin Coin, in order to obtain information about the price movements of the metaverse tokens they want to prefer.

The findings of the study will help potential investors make more informed decisions when evaluating metaverse token investment decisions. Investors and portfolio managers should prefer different investment instruments (assets such as commodities, foreign exchange, stock, crypto, etc.) along with metaverse tokens in their portfolio diversification processes, for rationality in their investments. The limitation of the study is that the token market, referred to as the new crypto niche (Vidal-Tomás, 2022), has not yet developed. Results may vary as the market evolves.

References

Ağırman, E. and Barakalı, O. C. (2022), "Finans ve Finansal Hizmetlerin Geleceği: Metaverse", Avrasya Sosyal ve Ekonomi Araştırmaları Dergisi (ASEAD), 9(2): 329-346.

Aharon, D. Y. and Demir, E. (2022), "NFTs and Asset Class Spillovers: Lessons from the Period around the COVID-19 Pandemic", Finance Research Letters, 47: 1-9.

Akkuş, H. T. and Çelik, İ. (2020), "Modeling, forecasting the cryptocurrency market volatility and value at risk dynamics of bitcoin", Muhasebe Bilim Dünyası Dergisi, 22(2), 296-312.

Akkus, H. T., Gursoy, S., Dogan, M. and Demir, A. B. (2022), "Metaverse and Metaverse Cyrptocuurencies (Meta Coins): Bubles and Future?", Journal of Economics, Finance and Accounting (JEFA), 9(1): 22-29.

Akkus, H. T, Gursoy, S. and Dogan, M. (2022), "The Volatility Spillover between NFT Investment Index and Global Technology Index: DCC-GARCH Application", Research Journal of Business and Management (RJBM), 9(2): 85-91.

Akkus, H. T. and Dogan, M. (2023), "Analysis of Dynamic Connectedness Relationships between Cryptocurrency, NFT and DeFi assets: TVP-VAR Approach", Applied Economics Letters, 1-6.

Alawadhi, K. M. and Alshamali, N. (2022), "NFTs Emergence in Financial Markets and their Correlation with DeFis and Cryptocurrencies", Applied Economics and Finance, 9(1): 108-120.

Ali, S., Naveed, M., Yousaf, I. and Khattak, M. S. (2024), "From cryptos to consciousness: Dynamics of return and volatility spillover between green cryptocurrencies and G7 markets", Finance Research Letters, 60, 104899.

Ante, L. (2021), "The Non-fungible Token (NFT) Market and Its Relationship with Bitcoin and Ethereum", Blockchain Research Lab. Working Paper Series No. 20: 1-9.

Antonakakis, N., Cunado, J., Filis, G., Gabauer, D. and De Gracia, F. P. (2019), "Oil and Asset Classes Implied Volatilities: Dynamic Connectedness and Investment Strategies", Available at SSRN 3399996. http://dx.doi.org/10.2139/ssrn.3399996, (Accessed 10.23.2023).

Aysan, A. F., Batten, J. A., Gozgor, G., Khalfaoui, R., & Nanaeva, Z. (2023), "Twitter matters for metaverse stocks amid economic uncertainty", Finance Research Letters, 56, 104116.

Bakas, D., Magkonis, G. and Oh, E. Y. (2022), "What drives volatility in Bitcoin market?". Finance Research Letters, 50, 103237.

Baur, D. G., Dimpfl, T. And Kuck, K. (2018), "Bitcoin, gold and the US dollar–A replication and extension", Finance research letters, 25, 103-110.

Bouoiyour, J. and Selmi, R. (2015), "Bitcoin price: Is it really that new round of volatility can be on way?", MPRA working paper.

Büberkökü, Ö. (2021), "Kripto Para Birimleri Arasındaki Getiri ve Volatilite Yayılımının İncelenmesi", Çağ Üniversitesi Sosyal Bilimler Dergisi, 18(2): 1-16.

Büberkökü, Ö. (2022), "Metaverse Coin'lere Dayalı Finansal Analizler", 5th International Izmir Economics Congress, İzmir/Turkey, 25-26 February 2022, 381-397.

Citi. (2022), "Metaverse and Money. Decrypting the Future", Citi GPS: Global Perspectives and Solutions. Citigroup, New York City, NY. https://www.citigroup.com/global/insights/citigps/metaverse-and-money_20220330 , (Accessed 02.11.2024).

Chaim, P. and Laurini, M. P. (2018), "Volatility and return jumps in bitcoin. Economics Letters", 173, 158-163.

CoinCecko, 2021, 2022, 2023 Annual Cyrpto Industry Reports, https://www.coingecko.com/tr/publications/reports, (Accessed 14.03.2024).

Coinmarketcap, https://coinmarketcap.com/tr/, (Accessed 01.17.2023).

CryptoDep, Top #Metaverse Tokens by Market Capitalization, March 10, 2022, https://twitter.com/Crypto_Dep/status/1501863458341638147, (Accessed 01.17.2023).

Dictionary of Terms of the Central Bank of the Republic of Turkey, https://www.tcmb.gov.tr/wps/wcm/connect/0ce9fa91-e7f2-433c-b5bd-2ba67f35f2c4/TCMB-TerimlerSozlugu.pdf?MOD=AJPERES&CACHEID=0ce9fa91-e7f2-433c-b5bd-2ba67f35f2c4, (Accessed 11.16.2022).

Diebold, F. X. and Yilmaz, K. (2009), "Measuring Financial Asset Return and Volatil-ity Spillovers, with Application to Global Equity Markets", Economic Journal, 119(534): 158-171.

Diebold, F. X. and Yilmaz, K. (2012), "Better to Give than to Receive: Predictive Directional Measurement of Volatility Spillovers", International Journal of Forecasting, 28: 57-66.

Diebold, F. X. and Yilmaz, K. (2014), "On the Network Topology of Variance Decompositions: Measuring the Connectedness of Financial Firms", Journal of Econometrics, 182(1): 119-134.

Dowling, M. (2022), "Is Non-fungible Token Pricing Driven by Cryptocurrencies?", Finance Research Letters, 44: 1-6.

Dwivedi, Y. K., Hughes, L., Baabdullah, A. M., Ribeiro-Navarrete, S., Giannakis, M., Al-Debei, M. M., Dennehy, D., Metri, B., Buhalis, D., …, Viglia, G. ve Wamba, S. F. (2022), "Metaverse Beyond the Hype: Multidisciplinary Perspectives on Emerging Challenges, Opportunities, and Agenda for Research, Practice and Policy", International Journal of Information Management, 66: 1-55.

Dyhrberg, A. H. (2016), "Bitcoin, gold and the dollar–A GARCH volatility analysis", Finance Research Letters, 16, 85-92.

Elliot, G., Rothenberg T. J. and Stock, J. H. (1996), "Efficient Tests for an Autoregressive Unit Root", Econometrica, 64: 813-836.

Gubadlı, M. and Sarikovanlik, V. (2023), "Kripto Para Piyasasında Volatil Davranışların Asimetrik Stokastik Volatilite Modeli İle Testi", Uluslararası Yönetim İktisat Ve İşletme Dergisi, 19(1), 61-82.

Güler, O. and Savaş, S. (2022), "Tüm Yönleriyle Metaverse Çalışmaları, Teknolojileri ve Geleceği", Gazi Mühendislik Bilimleri Dergisi, 8(2): 292-319.

Horky, F. (2023), "The metaverse hype: identifying bubbles and comovements of metaverse tokens", Journal of Chinese Economic and Business Studies, 1-25.

https://tr.investing.com, (Accessed 10.23.2023).

Karim, S., Lucey, B. M., Naeem, M. A. and Uddin, G. S. (2022), "Examining the Interrelatedness of NFTs, DeFi Tokens and Cryptocurrencies", Finance Research Letters, 47: 1-8.

Kumar, A. S. and Anandarao, S. (2019), "Volatility spillover in crypto-currency markets: Some evidences from GARCH and wavelet analysis", Physica A: statistical mechanics and its applications, 524, 448-458.

Lee, L. H., Braud, T., Zhou, P., Wang, L., Xu, D., Lin, Z., Kumar, A., Bermejo, C.& Hui, P. (2021), "All one needs to know about metaverse: A complete survey on technological singularity, virtual ecosystem, and research agenda", Journal of Latex Class Fıles, 14(8), arXiv preprint arXiv:2110.05352.

Mystakidis, S. (2022), "Metaverse", Encyclopedia, 2: 486-497.

Pinto-Gutiérrez, C., Gaitán, S., Jaramillo, D. and Velasquez, S. (2022), "The NFT Hype: What Draws Attention to Non-Fungible Tokens?", Mathematics, 10(335): 1-13.

Sert, T. (2019), Sorularla Blockchain, Blockchain Türkiye, Türkiye Bilişim Vakfı Yayını, https://bctr.org/dokumanlar/Sorularla_Blockchain_Turan_Sert.pdf, (Accessed 12.05.2022).

Sert, T. (2022), Sorularla DeFi-Merkeziyetsiz Finans, İstanbul: Tefrika Yayıncılık, https://indd.adobe.com/view/5b99bb77-877f-47f7-a881-33ef427205b6, (Accessed 12.05.2022).

Sonmezer, S. and Çelik, G. G. (2022), "How Returns of Metaverse Tokens are Interrelated?", International Journal of Social Sciences, 8(1): 213-223.

Steffen, J. H., Gaskin, J. E., Meservy, T. O., Jenkins, J. L. and Wolman, I. (2019), "Framework of Affordances for Virtual Reality and Augmented Reality", Journal of Management Information Systems, 36(3): 683-729.

Şenol, Z., Gülcemal, T. and Çakan, O. (2022), "Kripto Paralarla Borsalar Arasındaki Volatilite Yayılımı", Ekonomi Politika ve Finans Araştırmaları Dergisi, 7(4): 925-943.

Vidal-Tomás, D. (2022), "The New Crypto Niche: NFTs, Play-to-earn, and Metaverse Tokens", Finance Research Letters, 47(1): 1-18.

Vidal-Tomás, D. (2023), "The illusion of the metaverse and meta-economy", International Review of Financial Analysis, 86, 102560.

Yousaf, I. and Yarovaya, L. (2022), "Static and Dynamic Connectedness between NFTs, Defi and Other Assets: Portfolio Implication", Global Finance Journal, 53, 100719.