Non-Fungible Token (NFT) Prices, Cryptocurrencies, Interest Rate and Gold: An Econometric Analysis (Jan. 2019-Aug. 2022)

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Abstract

In May 2014, the animation "Quantum" was the first work to be associated with a non-fungible token (NFT) type certificate. As of 2020, the market has evolved considerably, with the millionaire figures and exponential growth typical of new disruptive technologies. Considering the recent rise of the NFT market, it is important to understand how it works and, above all, the determinants of the prices of NFTs are highlighted. Based on a detailed analysis of this new market, a GARCH multivariate econometric model is applied in order to assess whether it is possible to identify the price determinants of NFTs, based on the behavior of the prices of cryptocurrencies (Bitcoin and Ethereum), the US interest rate and the price of gold. The research is based on the study by Dowling (2022a), which sought to analyze relations between the prices of NFTs and cryptocurrencies. The results found coincide with the prices of NFTs that are similar and independent of cryptocurrencies, the interest rate and the price of gold, some specific differences to identify a determined period.

Keywords: NFT, Cryptocurrencies, price, multivariate GARCH

1. Introduction

In May 2014, the animation "Quantum", by artist Kevin McCoy, was the first work to be associated with a non-fungible token (NFT) type certificate, even before the phrase was coined. An NFT is a certificate of ownership related to any type of digital product, such as an image, photo, or text, among others. Less than 10 years after Quantum's "certificate of authenticity", Sotheby's (one of the most important international auction houses, specializing in art) sold the NFT for US$ 1.4 million.

Especially since 2020, the market for NFTs has evolved considerably, with the millionaire figures and exponential growth typical of new disruptive technologies. Just as an example, the first tweet was sold as an NFT for more than US$ 2.9 million by the president of Twitter himself in March 2021. In June 2021, the first all-Brazilian NFT art auction took place, with the auction by Twitter of work of the plastic artist Bel Borba, which generated a collection of R$13,000.00.

NFTs are, therefore, digital works of art that contemplate a series of subtypes of works registered on blockchain chains, in the same way as digital currencies such as Bitcoin, Ethereum, etc. The registration of property in a blockchain ensures, due to the intrinsic characteristics of the system, the reliability and guarantee of inviolability of the property of the asset. The market for NFTs is broader than that for art, as practically everything that is in a digital medium can be recorded in the form of an NFT, such as videos, GIFs, music, literal works, and games, among others.

Considering the recent rise of the NFT market, it is important to understand its functioning and, above all, the determinants of NFT prices, in view of the impact of this new market on the world of technology: like many other disruptive technologies, it has been experiencing exponential growth, and may even expand the opportunities for action in the context of the Brazilian economy. The interpretation of the dynamic behavior of NFT prices contributes to a series of issues, such as the development of the market for entrepreneurs and the possibility of diversifying portfolios for investors.

This article is organized into five sections, in addition to this Introduction. The next section covers the theoretical framework, with an emphasis on the functioning and evolution of the NFT, blockchain and cryptocurrency market, in addition to the analysis of possible NFT price determinants. In Section 3, the research methodology is

presented, with an emphasis on the data and the multivariate econometric model of volatility (multivariate GARCH). In Section 4, the results obtained from the econometric model estimated in light of the theory developed are presented, followed by some final considerations in Section 5.

2. Theoretical Framework

2.1 The NFT Market and Its Recent Evolution

An NFT begins, according to Dowling (2022a), with the registration of ownership of a digital asset on a blockchain, usually on an Ethereum network, and from there it can be traded, upon change of ownership and payment of the cryptocurrency received and registered on the blockchain. An NFT can have any digital asset as its object, the most common being works of art.

In a recent approach, Chohan (2021) aimed to analyze the NFTs in order to detect whether or not their characteristics can actually add real value, including due to their scarcity, as is the case of the NFTs of art. According to the author, in December 2020, the trading of NFTs generated US$12 million, and, just two months later, it increased to US$ 340 million. In a recent auction, a piece of tokenized art was valued at $69.3 million, making it the most expensive piece auctioned off in the history of digital art. The work "Everydays: The First 5,000 Days", by the American artist Beeple, consists of a collection of drawings and animations made during 5,000 consecutive days by the artist. Numerous artists are managing to digitally monetize their art with the new technologies available. Chohan (2021) analyzed the NFT market from 2015 and found that many had remained unsold until 2021. The author highlighted, however, that from 2021 onwards there was significant growth in this market.

Chohan (2021) found that NFTs have their value and scarcity related to the way they are treated to generate interest, exploring different fields, such as music, sports, and visual art. The big challenge, according to the study, is to generate and maintain this interest and value to be attractive in this niche market, which is that of tokenizable digital assets. According to Dowling (2022a), the market for NFTs grew to around US$550 million by the end of March 2021 in terms of NFTs transacted.

Figure 1 explains, didactically, the characteristics of an NFT and a traditional work of art. The figure, which is also an NFT, was developed by a researcher in the field of design at an Italian university, Mario Taddei. The figure shows Leonardo da Vinci's famous painting, which is "from the real world", unique and non-fungible, "situated" in the Louvre Museum. The famous Mona Lisa has an estimated value in Euros and is also linked to the world of traditional money that is fungible, such as dollars or gold coins. The NFT, which appears on the right side of the Figure, is from the "digital world", also unique and non-fungible, "situated" in a virtual gallery, OpenSea, which is one of the platforms where it is possible to buy and sell NFTs. NFTs are traded in digital currencies, the most common being Ethereum. Digital currencies, in turn, use blockchains, as do NFTs, and constitute "digital money", fungible like the Dollar and the Euro.

The NFT market emerged as an offshoot of new applications from the digital currency market, especially as both rely on blockchain. Blockchain is a community or decentralized network of users whose governance of encrypted data is based on technology. Blockchain first gained popularity as the protocol behind the Bitcoin cryptocurrency, according to Regner et al. (2019).

In the course of the last few years, it has become clear that the blockchain has allowed the emergence of a wider range of applications – a development that is mainly attributed to the possibility of running pieces of software code on a blockchain, according to Beck et al. (2016). Being called "smart contracts", a term coined by Nick Szabo (a famous jurist and cryptographer) in 1994, blockchain allows parties who do not know each other to carry out transactions securely. Correct execution is ensured by a consensus protocol, which runs on all nodes participating in the blockchain and provides consistency (Regner et al., 2019).
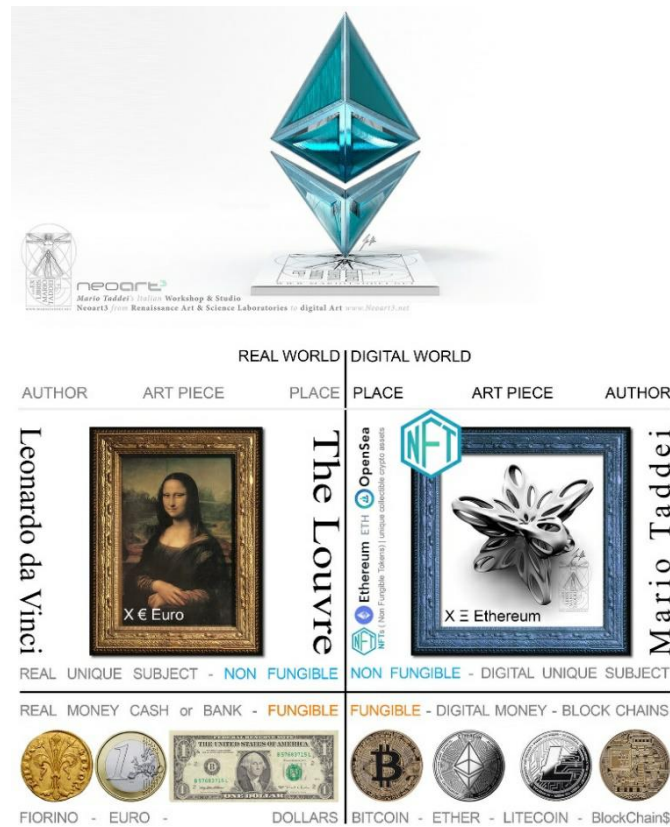
Figure 1. Characteristics of a Real World vs. Digital World art piece

Source: Taddei (2021).

Blockchains are distinguished by the way they are managed and maintained and can be operated with and without permissions. Permissionless blockchains do not belong to anyone other than the community that manages them and are managed by their users. In permitted systems, the administration is centralized, and they have a limited number of parties, that is, the entity that operates the network can also determine who can access it. In other words, a "manager" maintains the network, although it is the users who use the chain to carry out transactions, as well as connect and accept new data entries (Suominen et al., 2018).

There are still many challenges to be overcome when it comes to blockchain, but it is possible to provide much more security and optimize many and varied businesses, (Suominen et al., 2018). Thus, NFTs are a new type of blockchain, unique and indivisible, which can serve to tokenize digital goods, prevent fraud and improve control over the secondary market of transactions (Regner et al., 2019).

Just for context, the first NFT-based application to achieve widespread adoption was an online virtual game called CryptoKitties. The game took up over 70% of the Ethereum network's transaction capacity at one point. Furthermore, it was in this game that the most expensive NFT, which represents the "kitty" property, in which different versions are traded, sold for over US$100,000 at the end of 2017 (Regner et al., 2019). From then on, artworks were tokenized. Other experiments were also conducted, such the tokenization of software licenses, luxury goods, and even cars, through the use of NFTs.

NFTs were created based on blockchain technology for a specific purpose – to represent ownership of digital or physical assets. The first NFT-based app to achieve widespread adoption was Cryptokitties, which is, as mentioned earlier, an online game where participants can buy and sell cards with collectible kitty images. The game deserves to be highlighted for clearly showing the concept of "digital scarcity". The rarer the characteristics of the kitten on a card, the higher its value. What guarantees the "rarity" and "scarcity" is precisely the blockchain technology and the digital property guaranteed by the registry, as an NFT. In this way, like gold and precious stones, the NFT's value is determined by "scarcity", which means that digital works (in this case a card) can reach very high figures.

Scholten (2019) brought a new approach to the question, as he sought to assess Ethereum crypto games, which

are an expanding and relatively unexplored area of the gaming industry. There is still no standard definition of crypto-games, but they generally mean games that store tokens, such as in-game items, on a ledger distributed in part or in full over a cryptocurrency network. This allows the exchange of in-game items for cryptocurrency, which can then be exchanged for regular currency. Games constitute the largest category of DApps, making up 47% of all registered DApps. DApps are decentralized applications, a modality that has been growing a lot and that does not have a responsible person, but that still ensures a high standard of security, since they are blockchain-based software.

Also according to Scholten (2019), the crypto game CryptoKitties is currently the third largest DApp in number of transactions. The term 'crypto-games' refers to games whose token allocation is stored in a distributed ledger on top of a crypto network. Crypto games share many similarities with free games. Specifically, both involve virtual currency that can be purchased with real currency. And psychologically, both free-to-play games and virtual currency crypto-games often compound what has been called a numerosity effect where multiple currencies and unusually divisible amounts prevent players from making intuitive value estimates. This can cause players to spend more than planned, given the obfuscation of real-world value. For example, in a free game, an in-game apple can cost 7 Gems (an in-game currency). Already 40 gems can cost 0.155 coins (another in-game currency) and one coin costs £250. In this case, calculating the cost of an apple in the game in real currency becomes non-trivial. In crypto games, in-game items and activities have similar fractional cryptocurrency costs, with a unit of a given cryptocurrency typically having a non-intuitive and fluctuating real exchange rate. Gaming in this mode typically involves a digital wallet – in short, a piece of software that allows individuals to transact electronically over a network, such as a cryptocurrency. After a player creates a digital wallet, cryptocurrency exchanges allow that player to spend real currency to buy cryptocurrency from other network users, which is then associated with the player's public key. Unlike most free games, in crypto games, in-game currency is often exchangeable and can be used to pay for other goods and services outside of the game and can be exchanged for real currency.

2.2 NFTs' Price Determinants

In a survey, Dowling (2022a) analyzed whether the price of a non-fungible token (NFT) is correlated with the price of cryptocurrencies. The author specifically analyzed the Cryptopunks market. Cryptopunks transactions started in 2017, when 10,000 characters were created and registered as individual assets on the Ethereum Blockchain. The characters were created for US$50 to US$100 each, until the year 2020. The values were gradually increasing, with a considerable growth in the beginning of 2021. In February and March of 2021, characters that had been released at US$ 100 are now traded at between US$20,000 and US$100,000.

Dowling (2022a) analyzed data extracted from coinmarketcap.com (Bitcoin and Ether) and nonfungible.com (Decentraland, CryptoPunks, AxieInfinity) related to transactions with Bitcoin and Ether. Ether was analyzed for its connection to NFT, and Bitcoin for its market size and for bringing volatility data. NFT data was gathered from secondary market trades in Decentraland, CryptoPunk and AxieInfinity tokens. Spillover tests were carried out between the cryptocurrency markets and NFTs using the volatility spillover method of Diebold and Yilmaz. Dowling also used wavelet techniques to investigate the co-movement between the two analyzed markets, finding that NFT pricing appears to be distinct from cryptocurrency pricing in terms of volatility transmission. Furthermore, weak evidence was found for spillover between the NFT markets, possibly due to their different asset classes. There is a co-movement between Bitcoin and NFT prices, but it is likely to be due to common factors driving these markets, such as sentiment and uncertainty.

Previous research has attempted to analyze the relations between digital currencies and NFT prices. Baur, Dimpfl, and Kuck (2018) investigated the relation between the price of gold, the dollar and Bitcoin. Their results suggest that gold and Bitcoin were completely different assets in terms of risk and return and that Bitcoin follows a volatility process distinct from the other assets, therefore not showing correlation with the other assets.

They contested the results of Dyhrberg (2016), who analyzed the volatility of Bitcoin in comparison with the price of gold and the behavior of the dollar and found evidence of similarities in the behavior of asset prices, even suggesting that Bitcoin could be used in eventual strategies of hedging. In another research, Guo (2021) sought to estimate the behavior of the Bitcoin price and concluded that the Bitcoin market has a different price behavior from the commodity market in general. Dowling's (2022a) and Dowling's (2022b) research is the main basis of what is intended to be done according to the current research project. Using a recurrent method of analysis of co-movements, which translates into the use of an econometric model of the multivariate GARCH type, it is expected to identify which variables are related to the evolution of NFT prices. The method will be detailed in its own section.

3. Method

3.1 Variables

For the application of the multivariate econometric model, which will be presented in the next subsection, the research will use daily data from the NFT market, cryptocurrencies, and macroeconomic and financial variables. All variables have a daily periodicity, with a period between the first business day of January 2020 and the last day of July 2022. The variables related to NFTs and digital currencies also have quotes that change on Saturdays and Sundays, given that transactions with digital currencies and NFTs can take place any day and at any time. However, as the other variables are quoted only on business days, it was decided to standardize the bases, restricting quotations to business days only. Therefore, the quotations on Saturday and Sunday were eliminated without prejudice to the behavior of the variables. The variables used, with their description and data source, will be presented below.

i) Bitcoin price: the series, denoted by Bitcoin and expressed in dollars with the last price quote of the day, was obtained from Coinmarketcap.

ii) Ethereum price: the series, denoted by Eth and expressed in dollars with the last price quote of the day, was obtained from Coinmarketcap.

iii) Axie infinity: consists of a collection of NFTs based on a virtual video game. In 2021, the collection, measured by the value of NFT sales, can be considered the largest in the world, having achieved sales of over US$40 million in a single month. The data obtained refer to the average daily value of sales expressed in dollars and the source is nonfungible.com. The series is denoted by Axie.
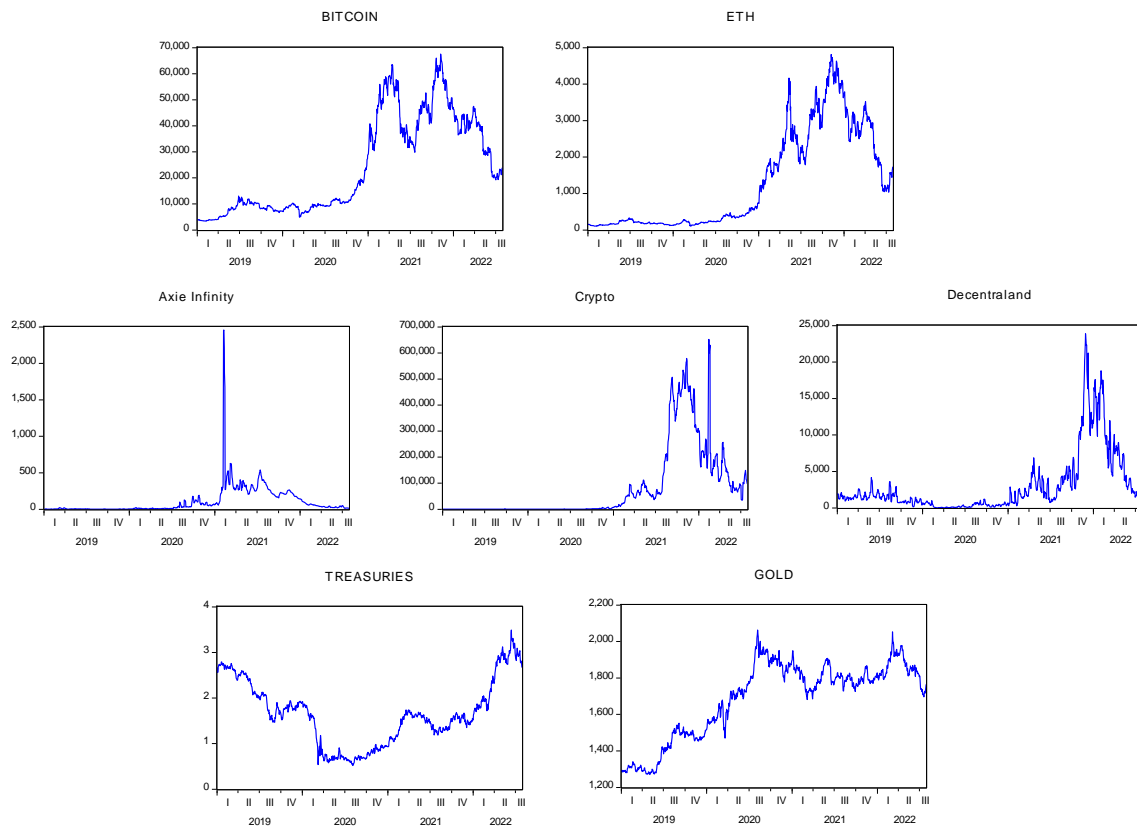

Figure 2. Variables graph

Source: Coinmarketcap.com, Nonfungible.com, Investing.com, Nasdaq and Fed.

iv) Decentraland: is a virtual game based on blockchain technology that allows the purchase and sale of virtual land based on NFTs. Some plots of land reach very high figures, close to US$1,000,000. The data obtained refer to the average daily sales value expressed in dollars and the source is the nonfungible.com website. The series is denoted by Decentraland.

v) Cryptopunks: were launched in 2017 as one of the first NFTs in a combination of art and technology in the age of social networks. It consists of a collection of 10,000 NFTs of pixelated avatars that reached the $1 billion

mark in sales in 2021. It is the second largest NFT project, behind only Axie Infinity in terms of sales figures. The data obtained refer to the average daily value of sales expressed in dollars and the source is nonfungible.com. The series, expressed in dollars, is denoted by Crypto.

vi) Gold price: the price of gold was used because it is considered an asset of intrinsic value, which shows an increase in prices especially when there is a loss of confidence in the international financial system and/or in scenarios of bank failures. The series is denoted by Gold, expressed in dollars per ounce, and obtained through the nasdaq.com website.

vii) Interest rate: the interest rate represents the cost of capital and one of the references for the international interest rate is the 10-year US government bond rate, denoted by Treasuries. The interest rate series was obtained from the website of the US Central Bank, the Federal Reserve.

Figure 2 presents the behavior of the variables. It is possible to notice that both Bitcoin and Ethereum show an upward movement from the fourth quarter of 2020, with a peak at the end of 2021, when a downward trajectory begins. There is a relatively common behavior between the movements of the two digital currencies, despite the differences between the peaks and valleys of quotes. Regarding the NFTs (Axie, Cryptopunk, and Decentraland), it is noted that until 2020 the price behavior was stable, with the beginning of a rise in prices for Axie in the second half of 2020 and for Cryptopunk and Decentraland in 2021. The price spike of Cryptopunk took place in February 2022, Decentraland's in November 2021, and Axie Infinity's in February 2021.

With regard to Treasury rates, it can be observed that, from the beginning of the period, January 2019 to the beginning of 2020, there is a drop in interest rates, which remain at low levels in 2020 with the coronavirus pandemic. and economic stimulus policies. At the end of 2020, an upward trend in the interest rate begins, which goes practically until the end of the analyzed period, when the interest rate peaked at 3.49% per year in June 2022. Regarding the price of gold, also shown in Figure 2, an upward trajectory is observed until 2020, with the peak in August 2020, when gold reached US$2063/ounce, followed by a period of time of relative stability in which the quotes were within an approximate band between US$1700 – US$2000. Although it is possible to observe common movements between the variables in several periods, it should be noted that there is the risk of spurious correlations between the variables, as highlighted by Granger and Newbold (1974). For this reason, as will be presented in the method section, the series will be transformed in terms of the return of each of the indicators to avoid estimating and analyzing spurious relationships.

3.2 Econometric Model

In view of the characteristics present in the returns of the time series used in the present study, such as the presence of volatility and heteroscedasticity clusters, an analysis using the Multivariate GARCH model is necessary. There are several distinct specifications in the context of the Multivariate GARCH model, such as VECH, BEKK, CCC and DCC. A detailed approach to the various specifications can be seen in Bauwens, Laurent and Rombouts (2006). Among the different possible specifications, the present study applied the BEKK specification, developed by Baba, Engle, Kraft and Kroner, which can be verified in Engle and Kroner (1995) and detailed in Vartanian (2020). The choice of specification was based on the criterion of parsimony, since it is the form that is characterized by the reduction of the number of parameters in the estimation of the model, in addition to being one of the most used in recent works.

In this context, the BEKK(1, 1, K) model has the following format:

$$H_t = C^{*'}C^* + \sum_{k=1}^{K} A_k^{*'} e_{t-1} e'_{t-1} A_k^* + \sum_{k=1}^{K} G_k^{*'} H_{t-1} G_k^* \tag{1}$$

Where C^*, A_k^* and G_k^*, are N x N matrices with C^* being an upper triangular matrix. The restrictions for identifying a BEKK model with K=1 are imposed on the matrices $A_{k,11}^*$ and $G_{k,11}^*$ in addition to the diagonal elements of C^*. Both the matrices $A_{k,11}^*$ and $G_{k,11}^*$, as the diagonal elements of C^* must be positive. Strictly speaking, the present research used a BEKK Diagonal model, in which the matrices A_k^* and G_k^* are diagonal matrices. It is a model that ensures that the conditional variance matrix is positive definite and that allows a reduction in the number of estimated parameters.

4. Results and Discussion

From the series obtained as described in the method section, the returns of each of the assets were calculated from the daily logarithmic difference. The results are shown in Figure 3. The vertical axis represents the return on each asset. It is possible to observe that Bitcoin had a daily positive return of 20% in 2019 and even showed a drop of more than 40% in a single day in the first quarter of 2020. In the first quarter of 2020, Ethereum also had a sharp drop, which reached almost 60% in a single day.
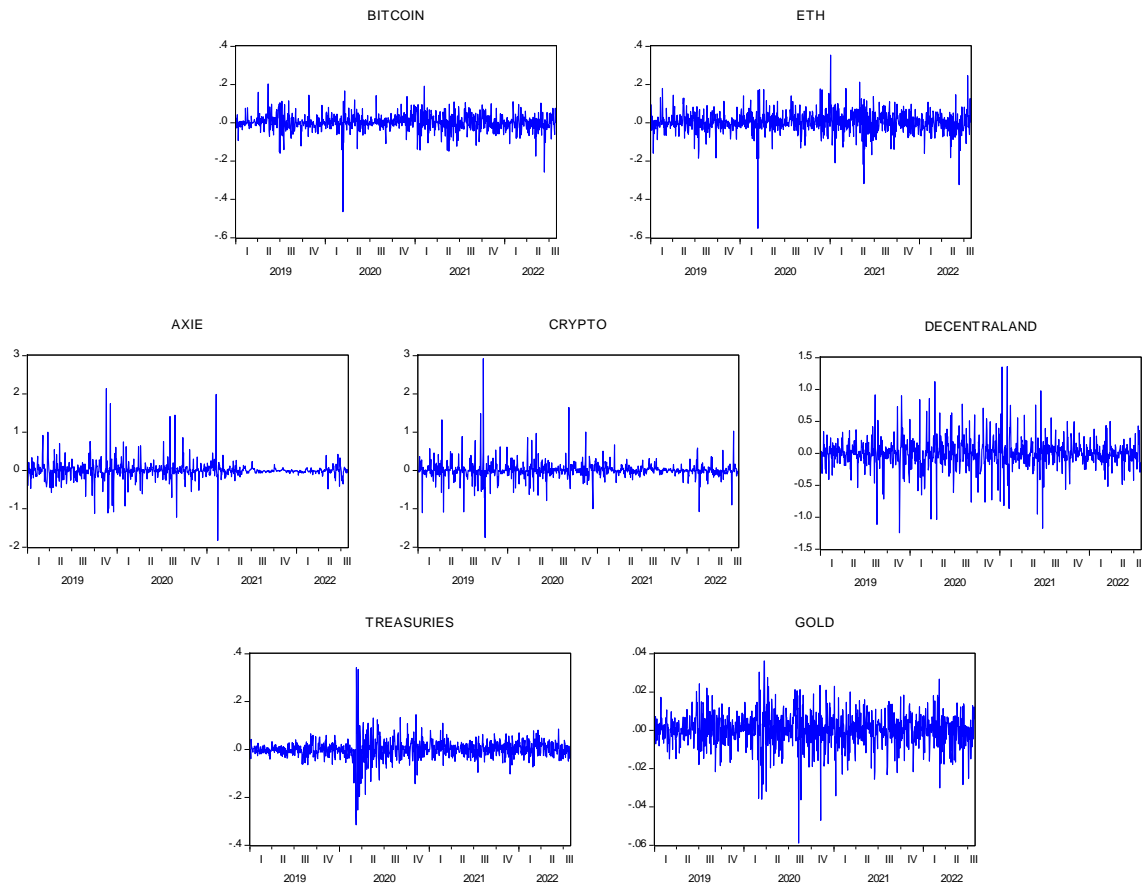
Figure 3. Calculated returns on assets

Source: Own elaboration.

With regard to NFTs, it is noted that the scales are even larger, which denotes even more volatility. In the case of Axie and Cryptopunks, the scales range from -200% to over 300%, which signals wide daily variability in NFT prices. Just as an example, in the fourth quarter of 2019, Axie's NFTs saw a 200% increase in a single day. In the first quarter of 2021, there was a 200% drop in a single day, which demonstrates high volatility in the prices of these assets.

About Treasuries, we note an increase in volatility, especially in the first two quarters of 2020, as an effect of the uncertainties arising from the COVID-19 pandemic and the reversal of expansionary monetary policy in the US after the subprime crisis. The price of gold, which is quite volatile, also had an increase in volatility in 2020, especially as it is an asset with intrinsic value to which investors are attracted in scenarios of inflation, crisis, and uncertainty.

Table 1. Correlation matrix

	Bitcoin	Eth	Axie	Cryptopunk	Decentraland	Treasuries	Gold
Bitcoin	1	0,82	0,02	0,01	-0,06	0,04	0,15
Eth		1	0,04	-0,01	-0,05	0,05	0,13
Axie			1	0,10	-0,09	-0,02	0,07
Cryptopunk				1	-0,01	0,02	0,05
Decentraland					1	0,02	-0,04
Treasuries						1	-0,28
Gold							1

Source: Coinmarketcap.com, Nonfungible.com, Investing.com, Nasdaq e Fed.

At the same time, a correlation matrix of the series returns was prepared, presented in Table 1. Although it is not possible to extract causal relationships from this correlation matrix, it is possible to identify a high correlation

between Bitcoin and Ethereum cryptocurrencies, of 0.82. With regard to other assets, there is practically no correlation, especially between cryptocurrencies and NFTs. There is no correlation even among the NFTs themselves. Also noteworthy is the fact that the price of gold is uncorrelated with the market for digital currencies and NFTs. The interest rate and the Treasury rate indicate some degree of negative correlation.

That said, a multivariate GARCH model was estimated with the objective of identifying the correlations between the assets and, thus, observing possibilities of price determinants of NFTs. In this context, Figure 4 presents the conditional correlation between NFTs and other assets. In general terms, it is possible to observe a weak conditional correlation between NFTs and assets, which suggests that the prices of NFTs are not determined, for most of the analyzed period, by the price of gold, the interest rate, or even Bitcoin and the Ethereum. The graphs suggest that NFTs follow particular volatility paths, in general, with price behavior independent of other variables.

The first line of charts in Figure 4 shows the conditional correlation between AXIE, Cryptopunk and Decentraland with Bitcoin. Overall, the conditional correlation between the three NFTs and Bitcoin was between -0.4 and +0.4, which indicates a weak correlation. In the first quarter of 2021 there was a peak of conditional correlation between AXIE and Bitcoin, which reached close to +0.8, but it was an isolated case and probably caused by the Covid-19 pandemic.

Regarding the conditional correlation of NFTs with the digital currency Ethereum, the general behavior is very similar to that observed in relation to Bitcoin, with a conditional correlation situated between -0.4 and +0.4. It was not until the end of Q3 2019 that a strong negative correlation between Cryptopunks and Ethereum occurred, reproducing the same in relation to Bitcoin. This situation, however, is due to an atypical behavior of Cryptopunks price volatility in the period in question.

The analysis of the volatility contagion between Treasuries and NFTs was not very different from what was expressed in terms of digital currencies since it was possible to verify low levels of correlation between the interest rate of Treasuries and the prices of NFTs. In almost the entire period analyzed, as shown in Figure 4, the conditional correlation was in the range between -0.4 and +0.4. There are, however, some specific periods in which the negative correlation was accentuated, such as in the third quarter of 2020, when the correlation between Axie and Treasuries was close to -0.8, which suggests that an increase in the interest rate was coincident with a sharp drop in the price of NFT. Such behavior, although with less intensity, can be observed especially in the third quarter of 2019 in relation to the NFTs Cryptopunks and Decentraland.

Finally, regarding the conditional correlations between the price of gold and the NFTs, low levels of correlation were also identified, normally situated between -0.4 and +0.4. In the third quarter of 2020, for the case of Axie and, at the end of the first quarter of 2020, for the case of Cryptopunks, there was an increase in the conditional correlation, which was above the level of 0.5, which suggests that, in this period, both assets had relatively more similar volatility. In the event of uncertainty about other assets, it is possible that investors have migrated in this period to gold and NFTs, but as it is not something systematic, it is not possible to treat specific cases as a strong connection between the prices of gold and NFTs.

The results found by the research converge with what was demonstrated by Dowling (2022a), who identified that the price movements of NFTs are different from the movements of cryptocurrencies, which, in the view of Dowling (2022a), appear to follow different pricing movements. The author also found evidence, albeit with a different period and method, of some co-volatility movement between digital currencies and NFTs. As shown through the analysis of conditional correlations in the current study, it was not possible to identify the presence of significant co-volatility movements between Bitcoin and Ethereum and the NFTs, except in some specific periods. With regard to the other assets used in this study, it is not possible to compare the results since Dowling (2022a) dealt only with the relation between cryptocurrencies and NFTs, without including the interest rate and the price of gold in the analysis.

In analyzing the relationship between the price of gold and Bitcoin, even before the existence of NFTs, Baur, Dimpfl and Kuck (2018) demonstrated that gold and Bitcoin were completely different assets in terms of risk and return, finding that Bitcoin follows a volatility process distinct from other assets and that it is not correlated with other assets. In this context, the present research is similar to the results of Baur, Dimpfl and Kuck (2018) in that it did not identify a strong conditional correlation between the prices of NFTs with the prices of gold, Bitcoin, Ethereum and interest rate movements in the USA. The relevant difference is that the authors tried to identify co-movements between assets and cryptocurrencies, given that NFTs did not even exist when the research was carried out.
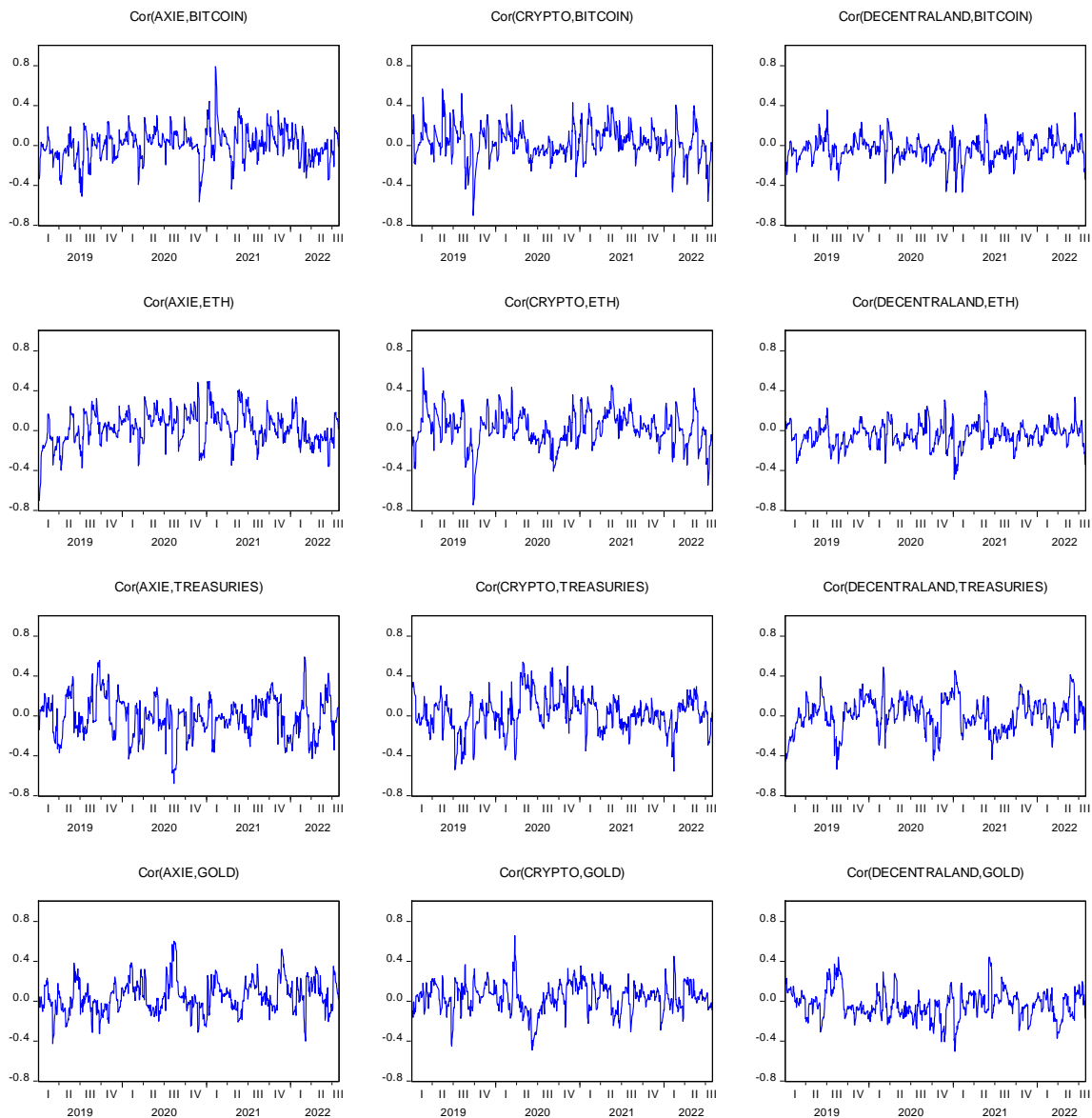
Figure 4. Conditional correlation between NFTs and Assets

Source: Own elaboration.

5. Final Considerations

The objective of the present research was to understand the functioning of the market for NFTs from an economic point of view and, above all, the determinants of NFT prices, in view of the impact of this new market on the world of technology that, like several other disruptive technologies, has been presenting exponential growth, and may even expand the opportunities for action in the context of the Brazilian economy. The interpretation of the dynamic behavior of NFT prices contributes to a series of issues, such as the development of the market for entrepreneurs and the possibility of diversifying portfolios for investors.

In order to achieve the objectives, a multivariate GARCH econometric model was used in order to evaluate the conditional correlation between the prices of NFTs and the variables selected as possible determinants, such as the quotations of Bitcoin and Ethereum cryptocurrencies, in addition to the price of gold and the interest rate in the US. Although the behavior of NFTs is typical of new disruptive technologies, with marked volatility and exponential growth, consistent relations were not observed in terms of NFT prices and cryptocurrency quotes. Nor were there any consistent relations between the interest rate and the price of gold with the NFTs.

Contrary to what was expected, the prices and volatility of NFTs seem to follow their own dynamics, regardless

of cryptocurrency quotes, the price of gold, and the US interest rate. The results are convergent with those found by Dowling (2022a). However, as the present research contemplated both the upward movement and the strong downward movement of NFTs in 2021 and 2022, there was an expectation that the conditional correlation between the variables would be close to 1, which did not happen. On the contrary, in almost the entire period analyzed, the conditional correlation between NFTs and the selected assets was mostly situated between -0.4 and +0.4, which suggests a weak relationship between the prices of NFTs and of assets. The analysis also converges with Baur, Dimpfl, and Kuck (2018), who carried out similar analyses considering only possible determinants of cryptocurrency prices, given that the NFT market was practically non-existent when their research was carried out.

A limitation of the present research concerns the availability and data format of NFTs. Despite the growth in trading volume, it was not possible to follow the price of certain NFTs over time. Instead, an average of the values of the different NFTs traded was used. In the future, as the market expands, it may be possible to track the prices of specific NFTs in the same way as the stock market. This limitation, however, does not diminish the relevance of the research, which was to demonstrate that NFT prices are not related to cryptocurrency quotes, interest rates, and gold prices, therefore following their own dynamics. At the same time, and even though it was not the main objective, the NFT market was identified as another market to be used as a source of possible risk diversification for investors, even though it has very pronounced volatility.

It may also be possible to include other macroeconomic and financial variables, such as stock market performance, the value of the dollar and oil prices in an attempt to identify other possible determinants of NFT prices. With a broader time series, and after the exponential growth behavior followed by a fall in prices, it may be possible to identify eventual determinants of NFT prices. Due to the unavailability of data in the current period, such possibilities are considered relevant in the agenda of future research.

Acknowledgments

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