

Financial contagion and identifying speculative frenzies: Unraveling price bubbles in cryptocurrency markets

Nora CHIRIȚĂ

Bucharest University of Economic Studies, Romania
nora.chirita@csie.ase.ro

Camelia DELCEA

camelia.delecea@csie.ase.ro
Bucharest University of Economic Studies, Romania

Ionuț NICA

Bucharest University of Economic Studies, Romania
ionut.nica@csie.ase.ro

Simona-Liliana CRĂCIUNESCU (PARAMON)

Bucharest University of Economic Studies, Romania
liliana.craciunescu@gmail.com

Ștefan-Andrei IONESCU

Bucharest University of Economic Studies, Romania
stefan.ionescu@csie.ase.ro

Abstract. *This research investigates the occurrence of financial bubbles in the cryptocurrency market and highlights the factors that may influence the formation of these bubbles. Three cryptocurrencies were analyzed: Bitcoin, Ethereum, and Cardano, and our findings showed that these cryptocurrencies exhibited potential bubbles during the three-year period under study, from 2020 to 2023. To detect financial bubbles, the Exponential Curve Fitting Model (EXCF) model was used. Events such as the Covid-19 pandemic and the Russia-Ukraine conflict were examined from the perspective of their potential impact on the cryptocurrency market and investor behavior. The study also illustrated how investors' behavior, whether rational or influenced by external factors, as well as internal factors such as panic levels and knowledge in the financial-economic domain, were analyzed.*

Keywords: financial bubbles, financial contagion, exponential curve fitting model.

JEL Classification: C5, C10, C58, D53.

1. Introduction

For their operations to be successful, cryptocurrencies depend on fundamental ideas like decentralization, cryptography, blockchain technology, and mining. In order to enable direct peer-to-peer transactions and do away with the need for intermediaries like banks, these principles will be explained in detail in this study. Using several methodologies that we will outline in the analysis methodologies and procedures section; the job is done with the intention of locating financial bubbles within the selected cryptocurrencies and creating a performing portfolio.

The research paper focuses on the following hypotheses: the existence of economic bubbles in the cryptocurrency market, notable variations in the behavior of the three cryptocurrencies during market growth and decline, the relationship between increased volatility and the profitability of the examined virtual currencies, and the impact of fundamental factors and investor sentiment on the emergence and development of economic bubbles. It tries to examine and test these hypotheses in order to better understand the phenomenon of financial bubbles by examining pertinent information and events from the chosen time period.

The research is structured into multiple sections. The first section presents conceptual and theoretical approaches to the financial market and describes fundamental concepts specific to the cryptocurrency domain. Chapter 3 describes how cryptocurrencies can be adopted and how they have been developed and operate. The next chapter conceptually describes the phenomenon of financial contagion that can also occur in the cryptocurrency market. Chapter 5 describes the working methodologies used in detecting potential price bubbles and financial bubbles.

The final chapter presents a case study conducted for three major cryptocurrencies in terms of market capitalization: Bitcoin, Ethereum, and Cardano. The Exponential Curve Fitting test was applied to detect potential financial bubbles. Each chapter includes a review of the current state of knowledge in the researched topic. The research paper concludes with a series of discussions, conclusions, and future research directions.

2. Conceptual approaches to financial cryptocurrency market analysis

According to The National Academies, even a superficial review of major international economic trends in recent decades reveals revolutionary changes in global financial markets. During the decades of the 1950s and 1960s, financial institutions and their regulatory bodies in industrialized countries experienced a period of relative autonomy from external influences. This period was characterized by strict restrictions on capital flows between countries, a common practice adopted by many nations, including the United States of America.

Significant developments (The National Academies, 1995) in the perspectives and circumstances of international finance took place throughout the 1970s and 1980s. This resulted in a sizable capital migration across international borders as a result of the convergence of numerous important causes. During this time, the organization and

operation of the international financial markets underwent a significant revamp. These marketplaces are currently very interconnected, and transactions have grown increasingly complicated. This is demonstrated by the listing of securities in numerous nations, international portfolio diversification, and ongoing trading of financial instruments on major stock exchanges.

As the name implies, financial markets are a particular kind of market that offer a means of buying and selling assets including bonds, equities, currencies, and derivatives. Even though they go by different names, such as "capital market," they all ultimately refer to the same entity. Simply explained, financial markets are a place where firms and investors can raise money to expand their operations and, ultimately, increase their chances of profit (Nica et al., 2021).

The financial market (Scarlat and Chiriță, 2019) is analyzed from a cyber perspective based on three major components: the money market, the capital market, and the foreign exchange market.

The money market (European Central Bank, 2023) is composed of both secured and unsecured segments, as well as derivative segments. In addition, the money market can refer to the market for short-term debt securities.

According to Caraganciu et al., capital markets, unlike foreign exchange markets, specialize in executing transactions involving assets with medium and long-term maturities. During that period, financial institutions and regulatory bodies managed available capital flows through internal economic agents or, in cases where capital needs exceeded internal financial resources, through external entities. This approach was adopted to cope with restrictions imposed by monetary authorities regarding access to financial resources within the country.

The capital market facilitates the efficient, secure, and timely transfer of available capital from economists, potential investors, and economic funds. The selection of real investment projects that prove to be profitable in terms of capital transfer (the evaluation function), the efficient and timely transfer of capital into the economy (the transfer function), and the safety of an organized capital transfer for investments that ensures liquidity and profitability based on assumed risk (the protection function) are the main areas of focus for financial policies aimed at achieving overall economic growth.

In the foreign exchange market (Ganti, 2023), currency transactions are conducted in pairs as currency values are interdependent. The relative value of one currency within a pair determines the purchasing power of the other currency. This dynamic relationship between currencies plays a crucial role in establishing price relationships in global markets. Additionally, it contributes to enhancing liquidity in other financial markets, thus contributing to the overall stability of the financial system.

The trade of cryptocurrencies, a digital form of money or financial asset built on blockchain technology, constitutes the burgeoning financial market segment known as the cryptocurrency market. Cryptography is used to protect transactions and regulate the generation of new units in virtual currencies known as cryptocurrencies.

The first and most well-known cryptocurrency, Bitcoin, was released in 2009, marking the beginning of the market for cryptocurrencies. Since then, thousands of new cryptocurrencies, including Ethereum, Ripple, Litecoin, Bitcoin Cash, and many others, have entered the market, greatly expanding its size. On a variety of exchange platforms, sometimes referred to as cryptocurrency exchanges, these cryptocurrencies can be traded.

The volatility of the bitcoin market is a key feature. The short-term volatility of cryptocurrency values can present traders and investors with both lucrative opportunities and considerable concerns. The fact that the cryptocurrency market is still relatively new and susceptible to certain influences like technology advancements, governmental laws, news media, and investor emotion is partly to blame for this high level of volatility.

In order to build a decentralized (without a middleman) digital ecosystem where users can trade value, cryptocurrencies were developed. According to the article "Bitcoin: A Peer-to-Peer Electronic Cash System" (Nakamoto, 2008), Satoshi Nakamoto was the first person or organization to define this kind of transaction.

A new coin was unveiled in 2008, but it was something entirely different this time. The first digital money was a thing called Bitcoin (Weiser, 2021). It was first introduced as software that operated on the Blockchain protocol, not by a well-known firm or bank, nor by any government. As usual, not many individuals were initially interested in adopting it because they didn't get the significance. Finding the answer can need some investigation.

Although Bitcoin was the first virtual currency to appear, there are now more than 7,600 different types of digital currencies accessible as of November 2020. Bitcoin was the first application to use the Blockchain technology once it was introduced.

Since its establishment in 2008, Blockchain 1.0 has existed for 15 years. It is an entirely decentralized database that is dispersed around the entire planet and cannot be held accountable because there is no central authority in charge of it. This technology is unaffected by interference or tampering and functions on all computer systems.

A blockchain is composed of several irreplaceable blocks. Its chain structure thus serves as the sole source of truth.

Since no humans are involved in the process of creating new blocks, the use of blockchain technology (Weiser, 2021) enables an entirely transparent administration system. Due to the fact that fresh blocks are automatically formed every 10 minutes, this efficiency is unrivaled. Additionally, the fact that these blocks are widely visible on all computers in the world enables full accessibility for everyone.

After launching Bitcoin in 2009, according to (Pinkerton, 2023), Nakamoto mined over 1.1 million Bitcoins before going missing in 2010. Gavin Andresen, formerly known as Gavin Bell, who wanted to decentralize the platform, took it under his authority indicated that there was no administrator, server, storage, or central authority. The blockchain was distributed to everyone, and all participants interacted peer-to-peer. The network's sole purpose was to validate and confirm transactions. As a result of the fresh uncertainty surrounding these stocks, Bitcoin's price has decreased.

On May 22, 2010, also referred to as "Bitcoin Pizza Day," the first actual Bitcoin transaction (Pinkerton, 2023) took place. Two Papa John's pizzas cost 10,000 Bitcoin to purchase for Laszlo Hanyecz. The cost of the pizza was roughly \$25. The two pizzas would have been worth \$630 million at the height of Bitcoin values in 2021.

3. Adoption of cryptocurrencies

We will concentrate on the most significant of the many elements influencing the future uncertainty of cryptocurrencies. First and foremost, the nature of emerging technologies is a crucial consideration. The capacity of specialist studies to keep up with the pace of rapid technological improvements is regularly exceeded. This discrepancy may cause ambiguity regarding trust and the long-term effects of cryptocurrency.

The widespread distrust of the new technology, particularly among governments that are hesitant to adopt it, is another factor. In addition, laws governing virtual currencies still need to be updated frequently to reflect changes in technology. This legislative ambiguity may make it unsafe for cryptocurrencies to operate.

The aforementioned Bitcoin version operates as an automated system for electronic money transfers (Originstamp, 2023), operating without the requirement for human participation during transactions or reliance on a reliable source of information. It enables people to exchange currencies without using a bank, whether it is privately or publicly operated. Through digital wallets, users can send money anonymously, and the complete transaction history is visible to all parties linked to the blockchain.

Next, we will analyze the process involved in mining and the security of transactions in the first level of blockchain. We will find reasons to reinforce the idea of adopting this mode of currency transaction by presenting the "proof-of-work" method (Frankenfield, 2023), the unique hexadecimal code present in each block, and the validation and rewarding of "miners".

3.1. Mining – proof of work

The practice of confirming data in a blockchain block by cracking a challenging algorithm is known as cryptocurrency mining (Frankenfield, 2023). The "miner" receives Bitcoin and fees as compensation for their efforts when they are the first to discover the right answer. However, as previously explained, the incentive falls as more Bitcoins are mined until there are 21 million Bitcoins in existence. After that, miners will only be paid for confirming transactions.

In the context of cryptocurrencies, mining explicitly refers to the procedure used to verify and add new transactions to the blockchain. The security and integrity of decentralized digital currencies like Bitcoin are ensured by this crucial feature.

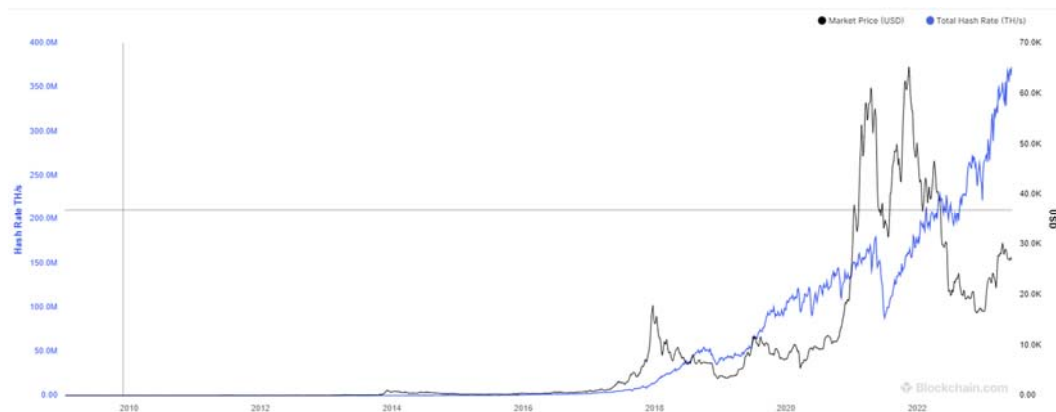
A common consensus mechanism used in several cryptocurrencies, including Bitcoin, is called Proof of Work (PoW). By eliminating fraudulent transactions and upholding a decentralized network, it is essential to ensuring the blockchain's integrity.

Miners compete to solve challenging mathematical puzzles in the PoW process. These puzzles demand a lot of processing power and are computationally demanding. A new block of verified transactions can be added to the blockchain by the first miner who figures out the solution to the puzzle. The reason why this procedure is called "mining" is because miners employ their computational power to determine the answer.

Miners repeatedly hash the data in the block using a cryptographic hashing algorithm until they discover a hash that satisfies particular requirements. Finding the right answer is challenging and resource-consuming since the hash must begin with a specific number of leading zeros.

When a miner discovers the right answer, they broadcast it to the network, where other nodes check the accuracy of the answer. The new block is uploaded to the blockchain if the solution is correct, and the miner is rewarded for their work with freshly created coins and transaction fees.

Figure 1. Evolution of Bitcoin coins (black line) and Hash Rate (blue line)



Source: Authors design using Blockchain platform, <https://www.blockchain.com/explorer/charts>

The PoW consensus technique makes sure that most of the computational power of the network is controlled by trustworthy nodes. This is due to the difficulty of the puzzles to solve, which makes it impractical for malevolent actors to take over the bulk of the network and alter transactions.

Despite being a reliable and secure consensus technique, PoW has significant limitations, chief among them being a high energy requirement. Concerns regarding the effects of mining activities on the environment arise from the requirement of a large quantity of electricity for the process of solving difficult mathematical riddles.

As a result, a few cryptocurrencies are investigating alternate consensus methods, such as Proof of Stake (PoS), that seek to accomplish the same security and decentralization objectives but using less energy.

3.2. The hash and the mining process

The concept of a hash lies at the core of the Bitcoin mining process. When the data in a block is hashed using the SHA256 (Secure Hash method) (Frankenfield, 2023) hashing method, a 64-digit hexadecimal number known as a hash is produced. This particular phase of the process is quick because it only takes a fraction of a second to generate a hash using an online SHA256 hash generator and insert the relevant portion of the material. This encryption technique is used by Bitcoin to create hash blocks.

Even with the aid of contemporary technology, decrypting a hash to retrieve the original content is a challenging task that takes a lot of work and time. A 64-digit hash could take a very long time to decode.

A particular mining application that creates a random hash is required for the Bitcoin mining process (Frankenfield, 2023). The term "unique number" is also used to describe the addition of a nonce to this hash. The nonce is set to zero when a miner begins the mining process. After then, the miner steadily increases the nonce with each try, starting at zero and going up to one, two, three, and so forth. The miner must repeat the operation if the hash produced by adding the block's contents and the nonce is higher than the target hash established by the network.

This process is carried out by every miner in the network until they reach a hash and nonce combination that is lower than or equal to the target hash. A new block is formed and the successful miner is rewarded with Bitcoin and any associated fees. The block is sealed, secured, and added to the blockchain once it has been filled with data, which typically takes up one megabyte.

There are numerous processes on the Bitcoin network that are only focused on mining. There is intense competition among them since the miner who finds the answer first receives the mining reward. Mining pools have been created as a result of this competition, allowing miners to pool their computer power to outperform rivals and improve their chances of winning the mining reward.

3.3. The regulated virtual currency prepared by the European Central Bank (ECB)

The introduction of a central bank digital currency (CBDC) in Europe has been proposed, according to the ECB (European Central Bank, 2023), in response to the growing demand for reliable and secure electronic payment methods. By involving the central bank, such a step would give the financial and payment systems a solid base. The adoption of a digital euro would also increase the euro area's monetary independence and the competitiveness and efficiency of the European payments sector. It should be mentioned that the ECB is now engaged in active discussions and in-depth study about the potential development of a digital currency known as Central Bank Digital Currency (CBDC).

A sort of currency known as Central Bank Digital Currency (CBDC) is one that is issued and governed by a central bank utilizing cutting-edge technologies like blockchain. Its goal is to act as a viable alternative to traditional fiat money, such as actual coins and banknotes. Numerous advantages can be realized by incorporating CBDC into the financial system, including but not limited to faster and more secure transactions, lower operating costs, and

improved accessibility, opening up access to financial services for people who were previously shut out of such opportunities.

A central bank introducing a digital currency raises a number of issues and factors that should be considered. These include concerns about personal data security, cybersecurity, and the potential effects on the current financial system. In order to ensure a successful and secure implementation of a digital currency, several factors must be carefully considered.

4. The phenomenon of financial contagion on the cryptocurrency market

In the context of the cryptocurrency markets, the financial contagion refers to the propensity for events or movements in one cryptocurrency to have an impact on the prices or actions of other cryptocurrencies. In the traditional financial market, the idea of the "herd effect" describes how investors are influenced by the behavior of the majority and respond as a result (da Gama Silva et al., 2019).

In recent years, there has been a renewed interest in analyzing volatility, with a particular focus on cryptocurrencies (Bhosale and Mavale, 2018; Naimy et al., 2021; Saleh, 2019). From the available studies, two main branches of literature emerge that examine volatility in cryptocurrency markets. The first line of inquiry concentrates on the volatility within different types of cryptocurrencies, while the second component of the literature explores the spillover of volatility between cryptocurrencies and traditional asset classes. These two areas of research offer insights into the dynamics of cryptocurrency volatility in various contexts and contribute to our understanding of their behavior in financial markets.

In light of the various types of contagion described in the specialized literature, the analysis of the phenomena of financial contagion might be directly tied to the analysis of the volatility of cryptocurrencies (Ferreira et al., 2019).

Using dynamic conditional cross-correlation and time-frequency correlation techniques, (Niyitegeka and Zhou, 2023) investigate the connections between stock markets in industrialized and emerging economies. There are two primary goals for the study. First, the authors examine whether the COVID-19 crisis, which affected both developed and developing nations, resulted in any pure (limited) financial contagion between cryptocurrency markets and stock markets. The study looks into how cryptocurrencies protected investors from stock markets before and during times of financial unrest brought on by the COVID-19 pandemic.

The scientists discovered that a rising correlation during the course of the crisis suggests that there is a risk of financial contagion between the stock market and the cryptocurrency market. The results also imply that during financial crises cryptocurrencies lose their hedging and safe-haven characteristics. (Nica et al., 2020; Nica, 2020)

There is now a heated policy debate surrounding cryptocurrencies. Unbacked crypto assets (like Bitcoin), decentralized finance (DeFi), and stable coins are a few of the numerous crypto-asset market categories. Although crypto-assets lack reference assets or inherent economic worth, they are frequently used as speculative instruments due to their extreme

volatility, high energy consumption, and role in financing illegal activities. This may have an impact on financial stability and poses issues with money laundering, market integrity, and consumer protection (European Central Bank, 2023).

5. Methodologies and techniques for identifying price bubbles

It is distinguished by a clearly defined economic cycle of quickly rising asset prices and market values. In essence, a bubble burst refers to a quick expansion that is followed by a dramatic decline in value or contraction in size.

Thus, the creation of financial bubbles is a process where the values of some assets rise quickly and diverge from their true value. These bubbles typically develop as a result of abrupt shifts in investment behavior. The fundamental cause of price bubbles, however, is still not represented by a generally applicable rule.

The positive discrepancy between real prices and underlying prices (reasonable values) of assets is the mathematical definition of a financial bubble. The following mathematical formula can be used to determine the actual price:

$$P_t = \sum_{i=1}^{\infty} \frac{E_t(d_{t+i})}{(1+r)^i} + b_t$$

Equation 1. The positive difference between base prices and actual prices

Where: P_t - represents the stock price at time t, E_t - represents the expected amount calculated on the basis of valid information available at time t, d_t - represents the dividends, r - represents the discount rate. The random bubble value that causes this condition to be set is determined by b_t .

$$b_t = \frac{E_t(b_{t+1})}{(1+r)}$$

Equation 2. The equilibrium price

The aforementioned formula has confirmed that, mathematically speaking, the idea of a negative bubble does not exist in the specialized literature. The positive bubble concept will, however, be employed in this research when the price increases unexpectedly quickly and the negative bubble concept will be used when we detect the impacts of a sudden collapse in the markets that were studied.

The rational expectations theory states that an asset's price may be calculated using the discounted cash flows it produces from the standpoint of rational economics. Market prices are established using information that is readily available to market participants and situation-specific economic models. This idea states that, barring market-wide misinformation that deceives investors, prices should correspond to an asset's intrinsic value. Unprofitable equities experience a spike in price as a result of increased demand that results from people purchasing them with the purpose to resell them for a profit in the future. An explanation for these phenomena is a sensible price bubble. Such bubbles grow

until they inevitably collapse, destabilizing all forecasting and planning attempts. (Chiriță and Nica, 2020a)

5.1. Exponential Curve Fitting Model (EXCF)

The EXCF (Exponential Curve Fitting) method, originally proposed by researchers Watanabe et al., in papers (Watanabe et al., 2007b) and (Watanabe et al., 2007a), is used to identify price bubbles in financial assets. The model is based on the estimation of the parameters $\omega_1(i, T_i)$ and $P_0(i, T_i)$ by analyzing the historical data T_i , with the aim of detecting periods of price divergence or convergence.

$$P_t - P_{t-1} = (\omega_1(i, T_i) - 1) \cdot (P_{t-1} - P_0(i, T_i)) + \varepsilon_t$$

Equation 3. Linear Regression

Where, P_t – represents the price of the financial asset at time t, and ε_t – represents the error term. To determine the optimal time interval T_i , an AR(p) model is first estimated on the original data:

$$P_t = \sum_{j=1}^p \phi_j P_{t-j} + \varepsilon_t$$

Equation 4. Simplified Autoregressive Regression (AR)

Using this AR(p) model, $N = 2000$ synthetic data are generated, starting with a minimum value of the interval T_1 and gradually increasing to the maximum value of the interval T_2 . The optimal time interval T_i is determined so that the estimated value of the parameter $\omega_1(i, T_i)$, obtained on the basis of the 2000 synthetic prices, is less than 1.

The method presented by Fantazzini uses a rolling estimating method to identify price bubbles or crash periods after the ideal time interval T_i is established.

(Fantazzini, 2019) utilized the "bubble" package in R to develop the EXCF algorithm to detect price bubbles. The initial observation in the data sample for the interval i, T_i was given to the parameter P_0 in this situation. As observed in equation 5, equation 4 has also been reformulated as an AR(p) equation without an intercept.

$$P_t - P_0(i, T_i) = \omega_1(i, T_i) \cdot [P_{t-1} - P_0(i, T_i)] + \varepsilon_t$$

Equation 5. The exponential price adjustment model

Based on the estimation of the parameters $\omega_1(i, T_i)$ and $P_0(i, T_i)$ using historical data and particular detection algorithms, the EXCF model and the price bubble detection algorithm constitute a valuable technique for the identification and study of price bubbles in financial assets. This approach can aid in comprehending and assessing price changes in the context of financial markets.

5.2. Generalized Supremum Augmented Dickey-Fuller Model (GSADF)

The study of logical bubbles, which are frequently linked to financial crises and economic recessions, has received a lot of interest. The rational bubble model is a popular theoretical

framework for comprehending the sharp increase in asset prices. The lower value of the asset is established by estimating the anticipated amount of future dividends, discounted to their present value. This model is based on the valuation of a rational bubble via the lens of present value theory. (Phillips et al., 2011) gave a thorough approach to this paradigm.

Recursive tests to find signs of explosive behavior in the time series $\{Y_t\}$, $t = 1, \dots, T$, were proposed by (Phillips et al., 2015). Recursive tests are used because the bubble component dominates price behavior. As a result, we can check for price bubbles immediately.

We consider the subsequent ADF regression:

$$y_t = \mu + \rho y_{t-1} + \sum_{i=1}^p \theta_{rw}^i \Delta y_{t-1} + \varepsilon_t$$

Equation 6. Augmented Dickey Fuller Regression

A test statistic was created by (Phillips et al., 2018) in a study to address the occurrence of many bubbles in a time series. They concentrated on the situation when the drift term is more than 0.5 specifically since it is thought that this is more important in real-world applications. The Generalized Supremum ADF (GSADF) test is the one they suggested. This test acts as a gauge to see if the time series exhibits explosive behavior.

In cryptocurrency markets and other financial time series data, the Generalized Supremum Augmented Dickey-Fuller (GSADF) model is a statistical method for spotting financial bubbles. The standard Augmented Dickey-Fuller (ADF) test, which is frequently used to check for unit roots in time series data, is extended by this method.

The GSADF model was developed to overcome some of the ADF test's shortcomings, especially in spotting explosive activity or price bubbles in the financial markets. The GSADF model makes it possible to identify explosive and super explosive behavior in the data, which point to speculative bubbles or unsustainable price increases.

The GSADF model is used by analysts and researchers to examine the behavior of cryptocurrencies and other financial assets, particularly during times of market instability and high volatility. Market participants can gain knowledge of market dynamics and potential hazards by spotting potential price bubbles, which will aid them in making wise investment decisions.

Although the GSADF model is a useful tool for spotting potential financial bubbles, it should be used in conjunction with other analysis methods to provide a complete picture of market circumstances because it is not a perfect strategy. Multiple strategies can be required to effectively predict market behavior because financial markets, particularly cryptocurrency markets, can be intricate and influenced by a variety of factors.

6. Analyzing cryptocurrency markets: identifying potential price bubbles and examining financial contagion

The way that financial transactions are handled in regular financial markets and cryptocurrency markets is different. While traditional financial markets are regulated by financial organizations and governments, virtual currency markets are decentralized and digital.

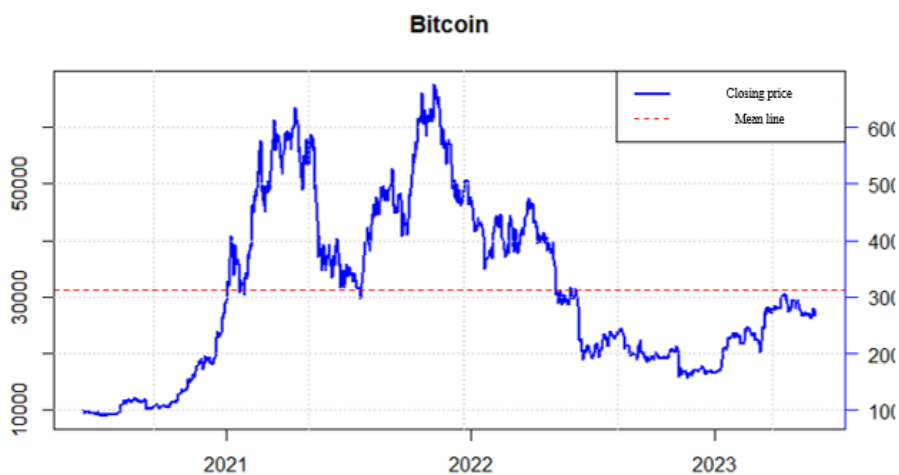
Virtual currencies are a recent financial innovation that have quickly garnered acceptance and recognition in the financial and investment sectors. Cryptocurrencies, which are digital currencies that use a technique called cryptography to safeguard transactions and control the creation of new cryptocurrencies, are traded on these exchanges.

Although Chainlink, Cosmos, Cardano, and other cryptocurrencies have significant market share, Bitcoin and Ethereum are the most well-known and actively traded cryptocurrencies that have contributed significantly to their widespread adoption and use in the digital currency markets. The variety of cryptocurrencies accessible for investment has expanded dramatically over time, providing investors with more options.

Cryptocurrency markets are known for high price volatility, meaning that prices can fluctuate widely in a short period of time, especially in response to unexpected events or industry updates. While this volatility can provide investors with significant profit opportunities, it can also expose them to significant risks. At the same time, it is necessary to pay special attention to the effects that can contribute to the emergence of the phenomenon of financial contagion.

The information that will be used to follow was extracted via <https://finance.yahoo.com> and then loaded into the RStudio platform for processing. Between June 6, 2020, through June 6, 2023, the cryptocurrencies Bitcoin, Ethereum, and Cardano will be examined.

Figure 2. Evolution of Bitcoin price (01.06.2020 – 01.06.2023)

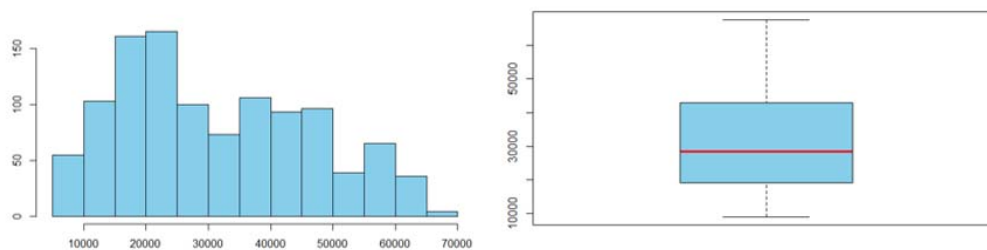


Source: Authors computation.

We see that the global effects of the coronavirus pandemic had an impact on the price of the Bitcoin cryptocurrency during 2020 and the first few months of 2021 (Ratten, 2022). A period of consolidation and little price volatility occurred during that time for Bitcoin. The price of Bitcoin grew dramatically in late 2021 and early 2022 as a result of the growing acceptance and popularity of cryptocurrencies and blockchain technology.

Significant occurrences like the listing of Bitcoin on well-known trading platforms and collaborations with trustworthy blockchain initiatives have boosted investor confidence. Additionally, this trend may have been significantly influenced by the global expansion of the cryptocurrency sector and investor interest in digital assets. Due to the hostile geopolitical environment (Ratten, 2022) or news about potential economic recessions, Bitcoin has seen major corrections since the second half of 2022 and up until the present.

Figure 3. *Bitcoin price histogram and boxplot*



Source: Authors computation.

The price distribution has an asymmetry to the left when the histogram is analyzed, which implies the existence of extreme values. A fast fall in price concentration, which follows a larger concentration of prices on the left side of the distribution, suggests the occurrence of extreme events. Leptokurtic distribution best describes this distribution.

The interquartile range is represented by a box, the median is shown by a vertical line inside the box, and the minimum and maximum values are shown by lines that protrude from the box. Outlier values are those that sit outside the whiskers and are displayed independently on the graph.

The sudden increases or decreases in the price of the Ethereum cryptocurrency (Appendix A) in 2020 and 2021 can be attributed to factors such as the increase in interest and general adoption of blockchain technology and cryptocurrencies during that time, just like with other cryptocurrencies, including Bitcoin.

After intense periods of growth, drops in the price of Ethereum are possible. These declines can be explained by selling by investors to take profits or by normal market adjustments.

In terms of seasonality, certain Ethereum price trends can be observed in the year 2022. For example, there may be periods when the Ethereum price experiences significant decreases or increases depending on changes in market sentiment, fluctuations in supply and demand, and the influence of general of the cryptocurrency market.

Table 1. Summary statistics for Bitcoin, Ethereum and Cardano

Summary Statistics	Bitcoin (BTC)	Ethereum (ETH)	Cardano (ADA)
<i>Min.</i>	-0.15974	-0.27200	-0.26009
<i>1st Qu</i>	-0.01445	-0.01972	-0.02613
<i>Median</i>	-0.00061	0.00199	0.00023
<i>Mean</i>	0.00148	0.00291	0.00286
<i>3rd Qu</i>	0.01733	0.02773	0.02607
<i>Max.</i>	0.18746	0.25947	0.32238

Source: Authors computation.

The following statistics are derived from the return data of Bitcoin, Ethereum and Cardano cryptocurrencies. They provide information about the returns given to them, namely the minimum value that represents the lowest level of profitability in the analyzed period for the returns of the 3 cryptocurrencies

The first quartile is a value that shows the lower limit of the lowest 25% of the data. It represents the point below which 25% of profits lie. For Bitcoin, Ethereum and Cardano, the values of the first quartile are -0.014, -0.019 and -0.026 respectively.

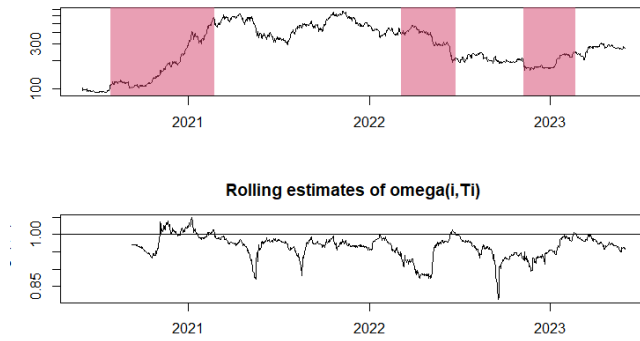
The median is the middle value in a set of data when arranged in ascending order. Divides the data into two equal halves. The median return for Bitcoin is -0.0006 and for Ethereum is 0.0019. Regarding the Cardano Cryptocurrency, the median value is 0.0002.

The return average for the examined cryptocurrencies is known as the mean. It is determined by adding up all of the values that were returned and dividing by the total number of observations. The average indicates the average return during the examined period and displays the typical value of the data set.

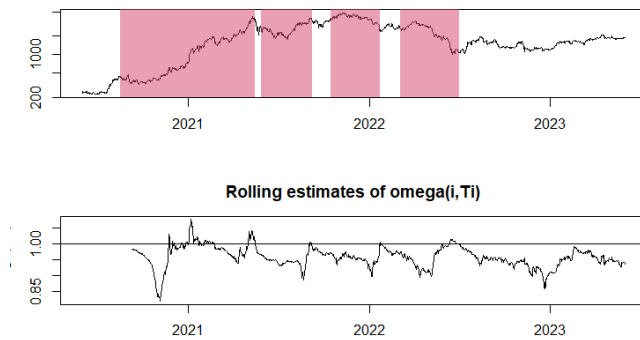
The value that 75% of the return dates fall within is represented by the third quartile. The highest value is displayed in the bottom 75% of the return distribution. The maximum value (Max.) shows the highest level of profitability in the data set for the returns of the 3 cryptocurrencies.

We note that virtual currencies have recorded lows and highs near the end of the coronavirus pandemic. This may suggest that at a time when uncertainty about the economy was high, the pandemic led to increased interest and adoption of cryptocurrencies as people looked for alternatives in the digital space. Therefore, the pandemic context played a significant role in determining the profitability of Bitcoin, Ethereum and Cardano during that period.

To determine potential financial bubbles on the cryptocurrency market, we will use the EXCF test which has a very short execution time compared to GSADF which can take several hours, however the accuracy is the same in both cases. We will use RStudio to find out what the result is for the analyzed cryptocurrencies.

Figure 4. *EXCF model for Bitcoin*

Source: Authors computation.

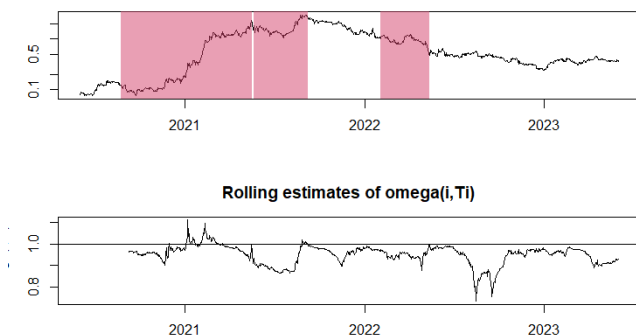
Figure 5. *EXCF model for Ethereum*

Source: Authors computation.

It can be seen in Figure 4 that 3 periods of potential financial bubbles formed for the Bitcoin Cryptocurrency were identified, periods marked in the graphic by the pink bands. The first period starting in 2020 and ending in mid-2021 has signs of the emergence of a positive financial bubble, justified by the rapid and significant growth of financial bubbles.

The second period from the year 2022 is a potential negative bubble justified by the sudden drop in the price of the cryptocurrency Bitcoin and the third, also present in the year 2023, by a positive financial bubble.

Regarding the emergence of the price bubble for the Ethereum cryptocurrency in Figure 5, we observe four periods of potential bubbles. Both negative and positive bubbles are observed.

Figure 6. *EXCF model for Cardano*

Source: Authors computation.

Regarding the appearance of the price bubble for the Cardano cryptocurrency in Figure 6, three potential periods of price bubble formation, also negative and positive, were detected.

It can be seen that through the EXCF test, price bubbles appear at key moments from a macroeconomic point of view. Thus, this analysis can also help us to realize certain patterns and seasonality regarding these cryptocurrencies. We can make an evaluation of them based on the bubbles found. Also, from an investment point of view we see that until the crash in the first quarter of 2022 there are many periods of accumulation. There were many opportunities there for those who wanted to profit, to sell to restore their capital and prepare for the worse period that was to come.

Regarding the phenomenon of financial contagion, within the cryptocurrency market, it can be understood as the tendency for events or movements recorded on one cryptocurrency to influence the prices or behavior of other cryptocurrencies. This can be similar to the concept of the "herd effect" in the traditional financial market, where investors are swayed by the actions of the majority and react accordingly. Since most cryptocurrencies are traded on public, interconnected exchange systems, price changes or significant events affecting one cryptocurrency can have an impact on investor sentiment generally and have an impact on other cryptocurrencies. The phenomenon of financial contagion and the emergence of financial bubbles in the cryptocurrency market are interconnected and can have mutual influences on the evolution of the market. When a price bubble forms in a digital asset or currency on the cryptocurrency market, traders and investors may become very interested in that asset or currency and increase their trading and investment in it in the hopes of making rapid money. This rise in interest and demand may have an impact on the value and volatility of the cryptocurrency, which might help a financial bubble form and grow.

7. Conclusions

Virtual currencies represent the exchange of an extremely volatile and uncertain market. The global outlook of the crypto market includes decentralization, which is achieved through blockchain technology. This eliminates the need for a central authority and provides transparency. This opens up opportunities for the technology to be used in various

industries such as finance, logistics, healthcare and more. The technological outlook for digital assets is promising, as this technology brings benefits such as security and efficiency in storing and transferring value. This technology has potential applications in identity management, electronic voting, supply chain tracking and other areas.

The cryptocurrency market can also contribute to financial inclusion and access to financial services in less developed or under-banked regions. Blockchain technology offers the ability to create and access financial services without traditional intermediaries, thus allowing people without a bank account or access to financial infrastructure to participate in the global economy.

As the cryptocurrency market continues to develop, there are also concerns about regulation, security and volatility. Adequate regulation can bring confidence and stability to the market, while security is essential to protect digital assets and user data. High price volatility is a characteristic of the crypto market and can influence investment decisions.

Both the COVID-19 pandemic and the conflict in Russia and Ukraine have the potential to cause unpredictability and volatility in the world's financial markets, including the market for cryptocurrencies. To shield themselves from the hazards and extreme volatility in the traditional market, investors and traders might turn to alternative investment assets. As a result, there may be a rise in interest in and demand for cryptocurrencies, which might push up prices and cause price bubbles.

Investors may look for secure assets or shelters to protect their wealth during periods of uncertainty and economic volatility. In such situations, cryptocurrency, particularly Bitcoin, has occasionally been viewed as "digital gold" and a viable alternative to fiat money. This need for financial security may increase demand for cryptocurrencies and have an impact on their value.

Some investors can hunt for speculative possibilities to make quick money during periods of economic unpredictability. Such investors, who wish to profit from substantial price fluctuations, may be drawn to cryptocurrencies because of their reputation for volatility. This pursuit of speculative investments has the potential to drive up the cost of cryptocurrencies and cause price bubbles.

Future research directions will include other models for testing financial bubbles, such as the Generalized Augmented Dickey Fuller model. In addition, we will try to capture potential financial contagion effects that are outlined by the emergence of financial bubbles.

Note

⁽¹⁾ For recommendations, suggestions or observations, you can contact the authors Ionuț Nica (ionut.nica@csie.ase.ro) or Ștefan Ionescu (stefion09@gmail.com).

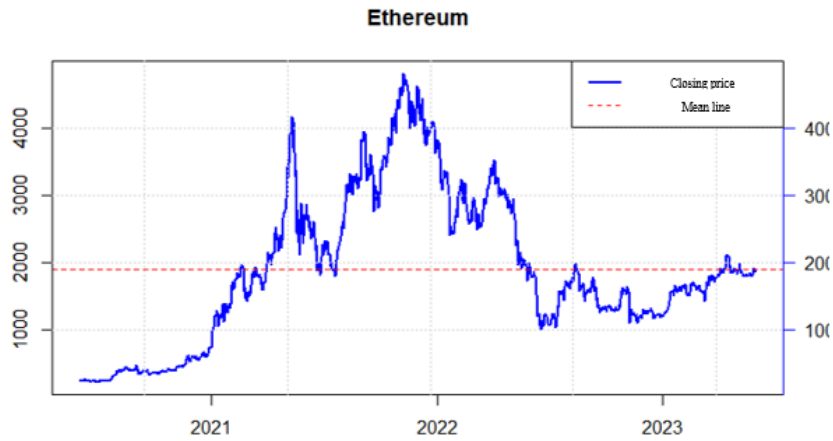
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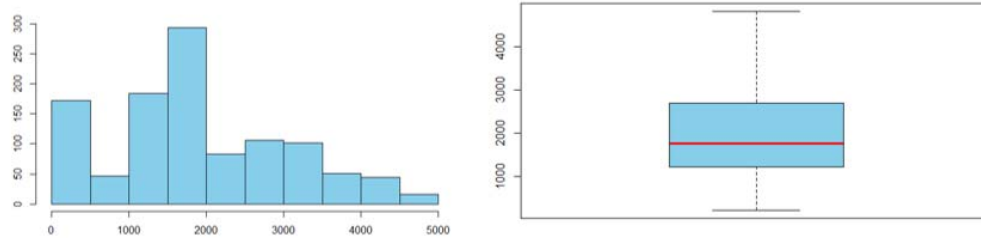
Appendix A

Figure A.1. Evolution of Ethereum price (01.06.2020 – 01.06.2023)



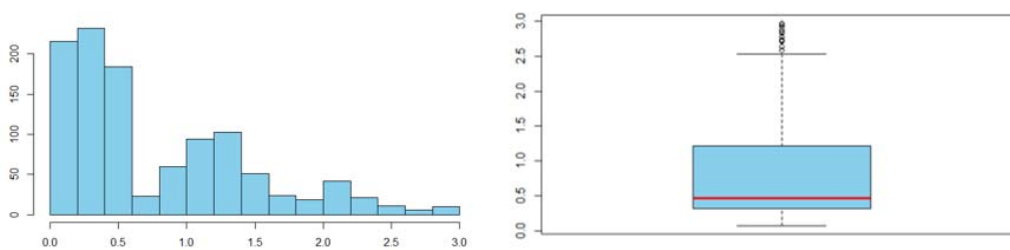
Source: Authors computation.

Figure A.2. Ethereum price histogram and boxplot



Source: Authors computation.

Figure A.3. Cardano price histogram and boxplot



Source: Authors computation.