




ARTICLE



<https://doi.org/10.1057/s41599-024-03220-0>

OPEN

Bitcoin's bubbly behaviors: does it resemble other financial bubbles of the past?

Sergio Luis Náñez Alonso ^{1✉}, Javier Jorge-Vázquez¹, Miguel Ángel Echarte Fernández¹ & David Sanz-Bas²

A number of financial bubbles have occurred throughout history. The objective of this study was to identify the main similarities between Bitcoin price behavior during bubble periods and a number of historical bubbles. Once this had been carried out, we aimed to determine whether the solutions adopted in the past would be effective in the present to reduce investors' risk in this digital asset. This study brings a new approach, as studies have previously been conducted analyzing the similarity of Bitcoin bubbles to other bubbles individually, but these were not conducted in such a broad manner, addressing different types of bubbles, and over such a broad time period. Starting from a dataset with 9967 records, a combined methodology was used. This consisted of an analysis of the standard deviations, the growth rates of the prices of the assets involved, the percentage increase in asset prices from the origin of the bubble to its peak and its fundamental value, and, finally, the bubble index. Lastly, correlation statistical analysis was performed. The results obtained from the combination of the above methods reveal the existence of certain similarities between the Bitcoin bubbles (2011, 2013, 2017, and 2021) and the tulip bubble (1634–1637) and the Mississippi bubble (1719–1720). We find that the vast majority of the measures taken to avoid past bubbles will not be effective now; this is due to the digital and decentralized nature of Bitcoin. A limitation of the study is the difficulty in making a comparison between bubbles that occurred at different historical points in time. However, the results obtained shed light and provide guidance on the actions to be taken by regulators to ensure the protection of investors in this digital asset.

¹DEKIS Research Group, Department of Economics, Faculty of Social and Legal Sciences. Catholic University of Ávila, 05005 Ávila, Spain. ²GILM Research Group, Department of Economics, Faculty of Social and Legal Sciences. Catholic University of Ávila, 05005 Ávila, Spain. ✉email: sergio.nanez@ucavila.es

Introduction

There is consensus in considering that several bubbles have occurred around Bitcoin (Wei, 2017; Kreuser and Sornette, 2018; Li et al., 2019; Holub and Johnson, 2019; Cross et al., 2021; Shu et al., 2021; Huber and Sornette, 2022). Some authors have proposed methods to detect them based on production cost (Xiong et al., 2020), while others have generated models to predict decline (crash) phases (Shu and Zhu, 2020). The difficulty lies in determining the long-term value of this cryptocurrency. Although the main component of demand for this virtual asset is speculation, there are grounds to assert that Bitcoin offers value for users (Van Alstyne, 2014; Ammous, 2018). The main properties of Bitcoin are that its money supply is rigid and that it is independent of the monetary policy of central banks. It is a real asset, as in the case of tulips, but of a digital nature. The expansive phases that this asset has passed through correspond to periods of monetary expansion and excess liquidity in the markets (Echarte Fernández et al., 2021), so monetary factors could be relevant to explain fluctuations in its quoted price, as in the case of other bubbles. It is interesting to study the periods of Bitcoin bubble behavior and its possible effects. Currently, the adoption of cryptocurrencies worldwide (led by Bitcoin) has not stopped growing. Not only has the growth of its price been exponential, but also the number of users, which was estimated at 5 million in 2016 and, in 2021, hovered around 220 million (Auer et al., 2022). However, at the time of writing this article, there are an estimated 300 million users worldwide and more than 10,000 cryptocurrencies (García-Corral et al., 2022). This implies that, globally, ownership stands at 14% of the population (Finder, 2023). Although its use among population strata is not homogeneous and is especially concentrated in men between 18 and 35 years old of a medium-high economic level (Alonso, 2023). The motivations of these people when operating with digital assets are diverse, although, in most cases, the scientific literature points to speculation (Auer and Tercero Lucas, 2022; Balutel et al., 2023); some authors even speak of similarities with “gambling games” (Johnson et al., 2023). However, when negative rumors arrive, the price drops considerably; this especially affects the youngest investors (Król and Zdonek, 2022).

In this context, the research hypothesis of this article can be articulated as follows: first, does the Bitcoin price show a trend similar to that observed in previous financial bubbles? The starting hypothesis is that there must indeed be parallels between Bitcoin prices and those of other speculative assets. After the empirical study, the hypothesis was confirmed. This research shows that there are significant coincidences between the behavior of Bitcoin prices and that of previous well-known bubbles. Therefore, thanks to this study, the idea that Bitcoin is an asset that tends to behave in the form of a bubble is reinforced. Secondly, what actions did the authorities and regulators carry out after the historical bubbles analyzed, and can we apply these formulas or actions to Bitcoin to prevent future bubbles?

In order to shed light on this issue, the article aims to undertake a comparative analysis between the ups and downs in Bitcoin prices and the behavior of five of the best-known bubbles in financial history: tulip mania (1634–1637), the Mississippi company bubble (1719–1720), the South Sea company bubble (1720), the New York Stock Exchange crash of 1929, and the dotcom bubble (1997–2001). The aim of this analysis was to find parallels between the behavior of Bitcoin prices and the behavior of these bubbles. Then, based on historical experience, we aim to consider what actions current regulators could undertake to mitigate these situations. This research offers new insights into the behavior of Bitcoin bubbles, both theoretically and practically. It is a unique study, with little precedent in economic literature. While previous comparisons have been made between Bitcoin and historical

bubbles like the tulip mania, this study takes a different approach. Buterin et al. (2020) suggest conceptual similarities between Bitcoin and the tulip bubble, while Taskinsoy (2019) highlights the role of new products in driving both bubbles. Leath (2019) compares Bitcoin's volatility and psychological factors with historical bubbles, albeit with a simpler methodology than ours. Ncube and Neuhaus (2023) argue that, while there are statistical similarities between Bitcoin and the tulip bubble, fundamental differences exist due to Bitcoin's technological nature and its impact on the financial system. They suggest that Bitcoin's price changes reflect a market in the process of discovering its true value.

This paper aims to approach the study of Bitcoin's bubbly behavior from a novel research perspective, by making a broader comparison, with data from various speculative processes. Most of the published studies to date have delved into the analysis of the internal and external factors of this cryptocurrency to explain price fluctuations (Sanz Bas, 2020; Nández Alonso et al., 2024). However, our research has analyzed whether there are significant statistical correlations between the evolution of Bitcoin prices and the behavior observed in the most relevant speculative bubbles of the past. This analysis has allowed us to determine the existence of a bubble pattern in Bitcoin based on the comparative analysis of a great number of financial bubbles. On the other hand, the application of different methods to the comparative analysis between selected historical financial bubbles and Bitcoin has expanded the volume of the existing scientific literature on financial bubbles. Finally, the proposed methodology and the results obtained represent a starting point for the construction of a novel research framework with the capacity to identify patterns of bubble behavior in other assets or reference periods.

The paper is structured as follows: After this introduction, the contextual framework is established where, based on the economic literature, an approach to the concept of bubble, its determinants, and the economic implications it entails is developed. Subsequently, the third section provides a characterization of the selected historical bubbles that will allow similarities with the behavior of the Bitcoin cryptocurrency to be found. Then, in Results, the methodological procedure is outlined, an empirical study on the bubble episodes that the Bitcoin price has had in comparison with the selected bubbles is described, and the results are shown. Finally, a discussion of these results is presented, and the main conclusions are drawn.

Literature Review

A brief review of historical economic bubbles. Economic history is rich in speculative episodes. Bubbles are processes in which there is a sudden overvaluation of an asset or set of related assets above what is justified by their underlying values Sornette and Woodard (2009). Thus, Kindleberger et al. (1987); Kindleberger (2016) considered that the origin of bubbles is usually in exogenous shocks that alter the expectations of individuals. These shocks can be of a diverse nature, such as a technological change, the discovery of a new natural resource, the appearance of a new financial product, the beginning of a war, the massive arrival of immigrants to a region, or substantial alterations in financing conditions Galbraith (2009). A change of this nature can generate a bubble if investors vastly overestimate the potential profit offered by these new situations. Rises in the quoted prices of the asset(s) attract new investors to this market, and this generates further price increases. This process (price increases—arrival of new investors—new price increases) is bound to continue for some time. The duration in time and the speed of the price increases of these assets depend on market expectations and on

the existing credit conditions, since the more economic agents can make leveraged investments, the greater the demand for the asset(s) Brunnermeier (2016); Hommes et al. (2008); Porter and Smith (1994). However, not every rise in the price of a good or asset implies that we are facing a bubble. On many occasions, the growth of share prices simply reflects the good economic performance of the issuing company in the market and the existence of expectations—in many cases, correct expectations—that this situation will continue in the future Brunnermeier (2016); Porter and Smith (1994). These speculative episodes usually end abruptly due to sudden changes in the expectations of economic agents accompanied by changes in financing conditions (Echarte Fernández et al. 2022). Generally, at a certain point in time, several investors realize that the asset (or assets) in question is not able to attract enough additional investors to that market to keep up with price growth, and, therefore, this leads them to sell their portfolio of assets in the market (Hommes et al. 2008). As more investors become aware of this situation and liquidate their positions in the market, the prices of the asset(s) in question tend to fall. As a result of these events, there comes a time when these bearish expectations spread to the rest of the investors and a general panic ensues.

Speculative bubbles are not a recent phenomenon. The following is a review of the five bubbles that are taken as references in this study: tulip mania (1634–1637), the Mississippi bubble (1719–1720), the South Sea bubble (1720), the New York Stock Exchange crash (1929) and the dotcom bubble (1997–2001). Studying the context of these bubbles will help to clarify the analysis of Bitcoin's bubbly behavior and, in turn, determine what actions the public authorities and regulators carried out to prevent their repetition. Tulip mania occurred between 1634 and 1637 in Holland which, at the time, was a commercial power due to the monopoly of the Dutch East India Company (VOC) and the stability of the Bank of Amsterdam. Speculation in tulip bulbs caused an accelerated growth in prices, giving rise to what is considered the first speculative bubble in history. This market operated through futures trading until it collapsed in February 1637. Garber (1989) considers that only the final phase of this speculative process can be understood as a bubble. The price of the common bulb, known as Witte Croonen, increased more than 25 times in the month of January 1637 and then collapsed in February of that year (French, 2014). Kindleberger (2016), however, does not consider it a prototype of a bubble because it did not have the monetary characteristics of bank credit expansion, unlike those bubbles that would occur from the 18th century onwards (Kindleberger, 2016).

Faced with such a situation, the government intervened in order to alleviate the consequences of the market crash. The measures adopted at the time to limit the effects of tulip mania and prevent its recurrence can be summarized in two measures. Firstly, local deputies meeting in Amsterdam decided on the cancellation of contracts drawn up before November 30, 1636. Those drawn up after that date were stripped of their performance in exchange for payment of 10% of what had been agreed to by the seller (Garber, 1989; Goldgar, 2008). This measure did not turn out to be very well received by the merchants, who intended to make a large profit. They opted to sue for breach of contract (Goldgar, 2008). Faced with an avalanche of lawsuits, the Dutch Court intervened by temporarily suspending the outstanding contracts. The Provincial Council of The Hague determined that this solution was somewhat futile. The second measure was taken in January 1638, when the Court established a committee dedicated to the enforcement of outstanding payments, known as the Commissarissen van de Bloemen Saecten (Commissioners of Floral Affairs) of Haarlem. In addition, the future contracts became optional, where the

payer had the option to pay the agreed full amount or refuse to fulfill the contract in exchange for paying a 3.5% commission (Garber, 1989; Goldgar, 2008).

The Mississippi bubble (1719–20) and the South Sea bubble (1720) occurred consecutively and had common elements. The first occurred in France with the speculation of the Mississippi Company's shares. The Scottish financier John Law (1671–1729) proposed to Regent Philip of Orleans the creation, in May 1716, of a private bank, the General Bank, to expand the money supply and thus revive economic activity (Bruner and Miller, 2018; Paul, 2020; Silvia, 2021).

On the other hand, John Law managed to acquire the Company of the West, which monopolized the trade between France and the French possessions in North America. With the desire to generate a large business project, this company acquired a large number of “public-private businesses” such as the Tobacco Monopoly, the Senegal Company, the Company of the Indies and China, the Africa Company, and the collection rights of all of France. This large holding company aroused the interest of French investors, and the share price of the Indies Company (as it was officially called, although colloquially it was called “Mississippi Company”) began to take off. John Law supported all further share issues with massive loans through the Royal Bank (Johannessen, 2016; Silvia, 2021; Velde, 2009). As a result of all this, the shares of the Company of the Indies went from 150 to 500 livres de tournois between 1717 and May 1719 and from 500 to 10,000 livres de tournois from June 1719 to January 1720 (Johannessen, 2016; Velde, 2009). Doubts about the company's profitability and the Royal Bank's liquidity problems resulted in the bursting of this price bubble during 1720. John Law did his best to force a bank corralito and to sustain the quoted price with liability issues of the Royal Bank, but, finally, he was stopped by the French authorities and the bubble ended up deflating (Silvia, 2021; Velde, 2009).

The South Sea bubble occurred in Great Britain in 1720. By the end of the War of the Spanish Succession (1701–1713), the English government was heavily indebted, and the budget deficit amounted to more than GBP 9 million (Sheeran and Spain, 2017). In this context, the creation of the South Sea Company was proposed, which was supposed to monopolize trade between England and the Spanish Crown's possessions in America.

The creditors of the English Crown were offered the conversion of their public debt securities for shares of this company. Their debt would be converted into perpetual debt, which would form part of the company's assets, and, in addition, hypothetically, they would have the privilege of benefiting from a monopoly on the fruits of trade between England and New Spain after the end of the war. This is how in, 1711 (two years before the end of the War of the Succession), this first exchange of debt for shares took place. The Crown greatly benefited because it improved its solvency tremendously and, in addition, managed to exchange thousands of creditors for just one. It should be noted that, in the Treaty of Utrecht (1713), which ended the war, the commercial privileges obtained by the English were very limited. In 1719, a second conversion of public debt into shares of this company took place under similar conditions. Finally, in early 1720, it was proposed that all public debt be converted into shares of the South Sea Company. The parliamentary process by which this conversion was approved, coupled with news of the Mississippi bubble developing in France, led to speculative fever. The share price rose from GBP 128 a share in January 1720 to GBP 1050 a share in June 1720 (Dale et al., 2005).

In August 1720, the share price of this company suffered a correction of more than 80%, leading to the ruin of many investors. This process of speculative euphoria also affected other companies, such as the East India Company or the Bank of

England, whose shares experienced a price rise and a subsequent correction. Likewise, during these months, there was a massive process of incorporation of companies by shares, some of which were simple swindles, seeking to benefit from the investment greed of the moment (Weston and Carswell, 1961). This process is reminiscent of the process of multiplication of cryptocurrency types that has taken place in recent years. The measures adopted at the time to limit the effects of the South Sea bubble by the English government basically focused on injecting capital to try to rescue the company. In the case of the Mississippi bubble, the French government harshly enforced legislation, leading to a wave of convictions against investors suspected of having obtained illegal profits (Silvia, 2021). The aim was to show that the state and the judiciary were pursuing such fraudulent behavior in order to prevent its generalization. In turn, in order to guarantee the savings of honest investors, the state had to assume the astronomical debt of the former company (Dale et al., 2005; Silvia, 2021).

The last bubbles were generated in the stock markets. The New York Stock Exchange crash of 1929 followed the “Roaring Twenties” in the United States. During the 1920s, there was strong economic growth driven by the introduction of abundant technological innovations, new products affordable to the middle classes, and new ways of working (Fordism, Taylorism, etc.). In various sectors of this economy, there were strong processes of investment and business transformation. There was also an accelerated process of real estate construction. For its part, the Federal Reserve and the American financial sector in general supported this economic expansion with abundant credit. All these factors contributed to an excess of optimism among investors, which was reflected in the New York Stock Exchange. During this decade, the Dow Jones stock index rose from 63.90 points in August 1921 to 381.17 in September 1929. This stock market bubble burst in October 1929 when many investors began to sell their shares. The stock price crash ruined thousands of investors and was one of the factors behind the Great Depression that the economy went through during the 1930s (Szostak, 2019).

The dotcom bubble occurred in the late 1990s when, after the emergence of the Internet, it seemed that all entrepreneurial initiatives in this field would be successful (DeLong and Magin, 2006; Goodnight and Green, 2010). However, in the year 2000, the shares of the Nasdaq stock index companies plummeted. It is estimated that, in 2002, 100 million individual investors had lost USD five trillion with the bursting of the so-called dotcom bubble (DeLong and Magin, 2006). The causes and origin of this bubble can be summarized by three phenomena: incomplete information, reputation, and speculation forming herd mentality (Xu, 2023). The irruption of the internet should be considered as the exogenous shock that gave rise to the bubble. Furthermore, as in the previous case, there was an environment of monetary laxity by the Fed and a context of high productivity (Echarte Fernández et al., 2022). The dotcom bubble is an ideal historical precedent for our purposes. The two spaces share the exuberance of “shoehorned” developing technology applied to problems that did not exist, excessive access to capital, ambitious promises without solid technology to back them up, and, finally, a great misunderstanding of the situation on the part of the investor (Fairchild et al., 2022; Xu, 2023). The dotcom crisis led to a series of measures to avoid a recurrence. Mainly, the power and supervisory capacity of stock market regulators were strengthened in many countries (Morris and Alam, 2008; Xu, 2023).

Once the characteristics of the previous bubbles have been described, the question can be raised as to whether these patterns of overvaluation have occurred in the case of Bitcoin and, if so, to which bubbles in economic history they are most closely related. It is true that, unlike for the previous bubbles, the great volatility

of this cryptocurrency has meant that it has partially recovered from the most important falls, and that it is still an asset that is present in the market. Although several studies indicate that its massive use and adoption respond to speculative intentions (Sanz Bas, 2020; Li et al., 2021; Milka, 2021; Auer and Tercero-Lucas, 2022), it is still a market asset.

Does Bitcoin behave as a bubble? It is often claimed that Bitcoin is an asset with bubbly behavior. Many researchers have tried to prove this claim, including, among others, Obayashi et al., 2015; Waters, 2019; Gronwald, 2021; Caferri et al., 2021; Li et al., 2022; Gemici et al., 2023; Podhorsky, 2024; and M’bakob, 2024. Essentially, in the academic literature, we can distinguish two different approaches.

A) The fundamental value-based approach. This approach is based on the understanding that the essence of a speculative bubble is the systematic deviation of the quoted price of an asset with reference to its fundamental value. This fundamental or intrinsic value is the value obtained by considering all the components surrounding an asset, including tangible and intangible elements. Some of the literature on the bubbly nature of Bitcoin has focused on this concept of fundamental or intrinsic value and its relationship to the quoted price (Cheah and Fry, 2015; Ciaian et al., 2015; Obayashi et al., 2015; Waters, 2019; Gronwald, 2021). This approach poses some difficulties when applied to Bitcoin, as it is an asset without a tangible backing and lacks observable future cash flows. In any case, part of the academic literature has studied the behavior of Bitcoin in relation to its assumed intrinsic value. In these calculations, various elements have been considered, such as production costs or the ability to substitute traditional monetary means.

B) The chartist approach. This approach considers that a speculative bubble exists when there is a prolonged increase in the market price of an asset and, subsequently, a sharp fall in its price. The advantage of this approach is that it eliminates the difficulty of determining the fundamental value of the asset in question and focuses on directly observable market prices. The bubbly dimension of Bitcoin has been extensively studied from this perspective. Within the literature, we can differentiate two types of study: on the one hand, studies on the environmental factors or “drivers” that influence Bitcoin price formation. The starting point of these studies is to consider that changes in Bitcoin supply and demand respond to a series of specific causes that can be determined. In many cases, it has been found that some of these factors influencing the supply and demand of this cryptocurrency have a high degree of volatility. This fact gives rise to abrupt changes in Bitcoin trading prices. There are studies focused on market manipulations, effects of monetary policy, interconnectivity between cryptocurrency markets, influence of the media, social networks on demand, etc. (Garcia et al., 2014; Urquhart, 2016; Gandal et al., 2018; Corbet et al., 2017; Bouri et al., 2019; Lee et al., 2020; Caferri et al., 2021; Li et al., 2022). On the other hand, there are studies on the statistical behavior of Bitcoin prices. This part of the literature has focused on applying econometric techniques to find patterns in Bitcoin price behavior. Many of these studies have built models that try to model the evolution of Bitcoin prices and be able to serve as bubble prediction tools and regulatory tools (Cheung et al., 2015; Fry and Cheah, 2016; Cagli, 2019; Geuder et al., 2019; Cretarola and Figà-Talamanca, 2020; Gemici et al., 2023).

This research is located within the field of research that studies the nature of bubbles according to a chartist approach and that focus on the statistical study of price quotations. Moreover, this research has as methodological antecedent the work of (Phillips et al., 2013), whose contribution consisted in the construction of

an econometric tool that studies the evolution of the price of a financial asset in relation to the behavior of different past bubbles. These authors did not conduct a study based on cryptocurrencies. In this sense, our contribution is focused on the study of the behavior of the Bitcoin trading price in comparison to past financial bubbles. There are many studies that analyze the causes and effects of speculative bubbles by applying the study of these processes to different areas such as the commodity futures market (Östensson, 2012; Miffre and Brooks, 2013; Lucey and O'Connor, 2013; Wöckl, 2019), the real estate market (Dreger and Zhang, 2013), or agricultural prices (Adämmmer and Bohl, 2015). Irwin et al. (2009) studied the boom and bust of the commodity futures market before the Great Recession. In addition, (Irwin and Sanders, 2011) analyzed the lack of empirical evidence behind the claim that index funds caused a bubble in commodity futures prices. Further, (Aasen, 2011) executed a similar study on the Oslo stock exchange listing and bubble behaviors of some of its assets. For their part, (Kasman and Carvalho, 2014) produced a similar study, but on Latin America and the Caribbean; (Altman and Kuehne, 2016) executed a similar study in the case of the bond bubble and (Bovet et al., 2018) carried out a study on the specific case of Bitcoin. A study by (Wang et al., 2019) focused on bubble behaviors over 26 representative economies for a period between 2000 and 2014. More recent are the studies of (Furi et al. 2022), for the case of Southern and East African economies, or that of (McDonald, 2022) for the case of the US stock market over the last 20 years. The study of Assaf et al. (2024) has recently analyzed the bubbles around fan tokens, highlighting that, out of 20 analyzed, 13 showed periods with bubble behavior. Finally, (Noussair and Tucker, 2016) indicate, in their study, that higher initial cash levels are indeed associated with higher prices when fundamental values are constant over time.

It should be noted that this is not the first time that Bitcoin's bubbly behavior has been compared with past bubbles. Taskinsoy (2019) compared the tulip bubble and the Bitcoin bubble and found that, in both cases, the listing prices were driven by the addition of new products to the investment market, i.e., new bulbs, in the case of the tulip bubble, and altcoins in the case of Bitcoin. Leath (2019) analyzed the presence of a Bitcoin bubble by comparing its price volatility and the psychological factors influencing its formation with that of two historical bubbles, the dotcom bubble and tulip mania; the methodology used for this study was simpler than that we propose in our research. Buterin et al. (2020), using a fundamental value approach, consider that Bitcoin has clear conceptual similarities to the tulip bubble, although they do not make an empirical comparison between the two bubbles. Demmler and Fernández Domínguez (2021) compared the phases of Bitcoin bubble behavior with the South Sea bubble quotes and found significant statistical evidence that both bubbles have similar behaviors. Fairchild et al. (2022) compared Bitcoin with the dotcom Bubble and used a methodology based on a practical application of the Emotional Finance framework; the authors found similarities between the Dot.com and Bitcoin emotion paths. Finally Ncube and Neuhaus (2023) argued that, despite the statistical similarities between Bitcoin and the tulip bubble, there are major differences in the underlying fundamental value of both products, since Bitcoin is a new emerging technology that has influenced the configuration of the international financial system and, according to these authors, the changes in its price are explained by the fact that the market is in a phase of discovering the real value of Bitcoin.

Materials and methodology

The research utilized data from various sources, including Investing.com, Dow Jones, and academic literature, to analyze the

behavior of Bitcoin bubbles alongside historical bubbles like tulip mania. Methodologically, it employed the Johansen–Ledoit–Sornette (JLS) model to detect bubbles, considering parameters such as the asset price deviation and time elapsed during bubble phases. Additionally, it utilized measures like the standard deviation, compound annual growth rate (CAGR), bubble index, and bubble size to compare the bubble characteristics across different periods and assets. Statistical correlation analysis, employing the Pearson correlation coefficient, was also employed to assess the relationship between cryptocurrency bubbles and selected historical bubbles. The main characteristics of the methodological approach adopted in this research are described below.

Materials. The materials used in this article have been extracted, in the case of the Bitcoin quotation, for the different periods considered, from Investing.com (2023) and are defined in USD and the daily quotation. In turn, the data relating to the Dow Jones Industrial Average (DJIA) have been extracted from the Dow Jones website, expressed in USD and the monthly quote (Dow Jones, 2023). In the case of the Nasdaq Composite, the data have been extracted from Investing.com (2023) and are defined in USD and the daily quote. Data relating to the South Seas Company and East India Company have been extracted from Frehen et al. (2013) and their daily quotation is expressed in GBP. Data concerning the Mississippi Company have also been extracted from Frehen et al. (2013), and their daily quotation is expressed in *livres de tournois*. Finally, the data concerning the tulip bubble have been extracted from Thompson (2006) and are expressed in a daily quote reconstructed by the cited author. These data mining methods have been previously used in cryptocurrency papers such as those of Włosik et al. (2022), Łęt et al. (2022) and Łęt et al. (2023). Table 1 shows the essential parameters of the bubbles under study.

All of the above data, shown in Table 1, have enabled the authors to generate a dataset of 9,967 records. This dataset is available for consultation as additional material in a digital repository. The link to access the repository is provided at the end of this manuscript.

Methodology. Our research takes into consideration elements of the Johansen–Ledoit–Sornette (JLS) model (Johansen et al., 2000) on rational expectations bubbles with finite-time singularity collapse hazard rates, which was developed to describe the dynamics of financial bubbles and collapses (Harsha and Ismail, 2019; Sornette et al., 2018). According to this model, bubbles occur when asset prices deviate significantly from their fundamental values due to irrational exuberance or speculative behavior. This model has been widely applied in the literature to detect bubbles and financial crises. Its successful adoption in the study of different financial bubbles supports its predictive capacity and its relevance to the objectives formulated in this study (Sornette et al., 2013; Ji and Zhang, 2023).

This model considers, among other variables, the time elapsed from the beginning of the bubble phase and its end (or the growth ratio) and the deviation of asset prices from their fundamental values, such as in the study by Sornette et al. (2018), and is replicated in the studies by Dąbrowski (2021) and Saranya (2022). However, we have complemented this model with other measures such as the standard deviation following Westphal and Sornette (2020) and Fruehwirt et al. (2021), and the bubble index following Astill et al. (2017), Shi and Wang (2018) and Zheng (2022).

Figure 1 shows the methodology applied. Thus, once the selection of bubbles has been made after the literature review, different methods are applied to compare the sample of Bitcoin bubbles with the rest of historical bubbles. Thus, we used the

Table 1 Basic data of the analyzed bubble sample.												
Bubble list	Type of asset	Index/ measure	Period considered	Date maximum	Days up to maximum (from start of period)	Maximum	Days up to minimum (from maximum)	% growth (from minimum)	Minimum before max.	Last quotation	% fall (from maximum)	Source
Bitcoin 2011	Cryptocurrency	USD	18 July 2010 to 1 January 2012	8 June 2011	325	31.9	164	31900.00	0.1	5.5	17.24	Investing.com
Bitcoin 2013A	Cryptocurrency	USD	1 December 2012 to 30 June 2013	10 April 2013	130	266	81	2094.49	12.7	98.1	36.88	Investing.com
Bitcoin 2013B	Cryptocurrency	USD	30 June 2013 to 30 November 2013	29 November 2013	152	1241.9	125	1612.86	77	452	36.4	Investing.com
Bitcoin 2017	Cryptocurrency	USD	25 March 2017 to 1 January 2018	17 December 2017	267	19870	15	1994.98	996	13921.5	70.06	Investing.com
Bitcoin 2021 A	Cryptocurrency	USD	27 September 2020 to 11 July 2021	14 April 2021	199	64778	85	591.2	10957	34580.6	53.38	Investing.com
Bitcoin 2021B	Cryptocurrency	USD	7 July 2021 to 12th, 2022	10 November 2021	122	68990.6	199	222.26	31040.8	31753.4	46.03	Investing.com
Crash of 1929	Shares	Quote/ Points	January 1928 to July 1932	August 30th, 1929	577	380.33	1035	191.52	198.59	42.84	11.26	Dow Jones Industrial Average
Dotcom	Shares	Quote/ Points	1 October 1998 to 31 October 2002	March 10th, 2000	526	5060.34	214	356.36	1420	1330.73	26.3	Nasdaq 100
Mississippi	Shares	Livras	6 August 1718 to 31 December 1720	8 January 1720	520	10100	358	3689.5	273.75	3640	36.04	(Frehen et al. 2013)
South Seas Company	Shares	Pounds Sterling	6 August 1718 to 31 December 1720	July 10th, 1720	704	950	140	840.71	113	185	19.47	(Frehen et al. 2013)
East India Company	Shares	Pounds Sterling	6 August 1718 to 3 January 1721	12 July 1720	326	420	175	222.52	188.75	150	35.71	(Frehen et al. 2013)
Tulips	Consumer goods	Thompson Index	12 November 1636 to 1 May 1637	3 February 1637	83	202	87	2269.66	8.9	8.9	4.41	(Thompson, 2006)

Source: authors' own elaboration based on data extracted from (Investing.com, 2023), (Dow Jones, 2023), (Frehen et al., 2013), and (Thompson, 2006).

Source: authors' own elaboration based on data extracted from (Investing.com, 2023), (Dow Jones, 2023), (Frehen et al., 2013), and (Thompson, 2006).

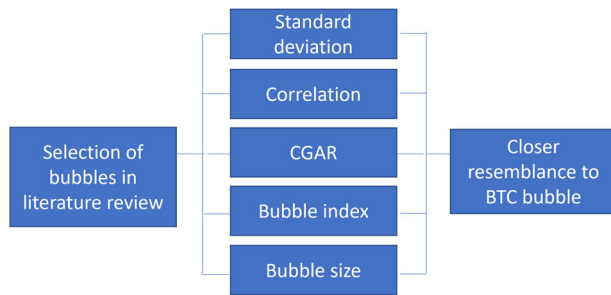


Fig. 1 Methodology applied. Source: authors' own elaboration.

comparison of deviations, the CGAR, the bubble index, the bubble size, and, finally, a statistical comparison of correlations. After all this, we were able to compare the greater similarity between the bubbles that are part of the study sample.

First, a comparison of standard deviations is made. These can be used to compare the volatility of an asset's price during a bubble, understood as the degree of variation in an asset's price over time. A higher standard deviation indicates a higher level of volatility, which is typical of a bubble. One way to use standard deviations to compare two bubbles is to calculate the standard deviation of the asset price during each bubble. A higher standard deviation during a bubble would indicate that the asset price was more volatile during that bubble, suggesting that it was a larger or more significant bubble. This method has long been used in various studies, such as the study by Caginalp et al. (2001) for the case of the 1929 crash, and that by Siegel (2003) for the 1987 crisis. The study by Preis and Stanley (2011) on the German DAX futures market, and the studies by Westphal and Sornette (2020) and Fruehwirt et al. (2021) on cryptocurrencies are further examples. The equation for the standard deviation is shown in Eq. 1:

$$\sigma = \sqrt{((x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \dots + (x_n - \bar{x})^2)/n} \quad (1)$$

where σ is the standard deviation; x_1, x_2, \dots, x_n are the individual observations of the asset price; \bar{x} is the mean of the observations; and n is the total number of observations. To compare the standard deviation of the two bubbles, the standard deviation of the asset price during each bubble would be calculated using the above equation and then the two resulting values would be compared. A larger standard deviation during a bubble would indicate that the asset price was more volatile during that bubble, suggesting that it was a larger or more significant bubble.

Second, the growth rate of the prices of the assets involved in each bubble is compared. This has been performed by calculating the compound annual growth rate (CAGR) of prices over a specified period of time. A higher CAGR indicates a faster rate of price growth and a larger bubble. The compound annual growth rate (CAGR) is a measure of the average annual growth rate of an investment over a specified period of time. It is used to smooth out short-term fluctuations in the performance of an investment, making it easier to compare the performance of different investments. This method has been used by Kanojia and Malhotra (2021) in the case of the Indian stock market, by Dąbrowski (2021) in the case of the stock market during the COVID-19 pandemic, and by Saranya (2022) for the cryptocurrency market. CAGR is often used to measure the performance of stock market investments, mutual funds, and other financial products. The CAGR formula is shown in Eq. 2:

$$\text{CAGR} = (V_f/V_n)^{(1/n)} - 1 \quad (2)$$

where CAGR is the compound annual growth rate; the terminal value (V_f) is the value of the investment at the end of the specified period; the initial value (V_n) is the value of the investment at the beginning of the specified period; and n is the number of years in the specified period. The CAGR is expressed as a percentage and represents the annualized growth rate over the entire period. It is calculated by taking the n th root of the total return (terminal value/initial value) and subtracting the value of 1.

Thirdly, the "bubble index" parameter was used. This index compares the current price of the asset with the historical average price. A value greater than one indicates a bubble. The bubble index is a measure that compares the current price of an asset with its historical average price. It is used to detect whether an asset is overvalued or experiencing a bubble. A value above one indicates that the asset is overvalued or in a bubble, while a value below one indicates that the asset is undervalued. This method has been used by Miao et al. (2019), Enoksen et al. (2020) and Agosto and Cafferata (2020) for the case of the cryptocurrency market. The bubble index equation is shown in Eq. 3:

$$\text{IB} = (P_n/\bar{P}) \quad (3)$$

where the Bubble Index (BI) is the index that compares the current price (P_n) with the historical average price (\bar{P}). The Current Price is the current price of the asset, while the historical average price is the average price of the asset over a certain period of time, often the most recent 5 or 10 years.

Fourth, the bubble size comparison has been used by Astill et al. (2017), Shi and Wang (2018), and Zheng (2022). For this, the percentage increase in asset prices from the beginning of the bubble to its peak was calculated. Thus, a larger percentage increase indicates a larger bubble.

Finally, and to complement the previous methods, statistical correlation was used. For this, the Pearson correlation coefficient was used to evaluate the correlation between two variables which, in our case, are the cryptocurrency bubble and the rest of the selected bubbles. This method was previously used by Kenett et al. (2012) for the Dow Jones Industrial Average (DJIA) from March 15, 1939, to December 31, 2010; by Ranganathan et al. (2018) for the case of the dotcom bubble; by Kyriazis et al. (2020) in the case of the cryptocurrency bubble; or, more recently, by Vidal-Tomás (2022) for the case of NFTs and tokens in the metaverse. Pearson's correlation coefficient, represented by the letter " r ", is a measure of the linear relationship between two variables. The Pearson correlation coefficient equation is defined as Eq. 4:

$$r = (n\sum xy - \sum x \sum y) / \sqrt{[(n\sum x^2 - (\sum x)^2) * (n\sum y^2 - (\sum y)^2)]} \quad (4)$$

where n is the number of observations; x and y are the two variables being compared; $\sum x$ and $\sum y$ are the sum of the x and y values, respectively; $\sum xy$ is the sum of the product of the x and y values; and $\sum x^2$ and $\sum y^2$ are the sum of the squares of the x and y values, respectively.

Results

The descriptive statistics of the sample can be found in Table A.1 in the Appendix. The variables Bitcoin 2011, 2013A and 2013B, 2017 and 2021B, Nasdaq, Old East Company, and South Sea Company present a positive asymmetric distribution. On the other hand, the variables Bitcoin 2021 A, Dow Jones Industrial Average, Mississippi, and Tulips present a negative asymmetric distribution. Regarding kurtosis, all the variables are platykurtic by obtaining a result lower than 3, except the Bitcoin 2011 variable, which is leptokurtic ($3.330 > 3$), although this is not a problem since a higher kurtosis does not imply a higher variance. In any case, the fact that there is a higher concentration of variable values far from the mean (tails), together with a lower

Table 2 Results.

	Standard deviation (σ)	CGAR****	BI**	Bubble size (%) ***
BTC 2011	5.7	647.56	7.62	31900.00
BTC 2013A	54.1	5117.94	3.75	2094.49
BTC 2013B	342.0	793.00	2.66	1612.86
BTC 2017	4394.7	58.85	3.93	1994.98
BTC 2021 A	16569.5	25.03	1.76	591.20
BTC 2021B	9256.3	9.91	1.51	222.26
DJIA	87.0	0.51	1.82	191.52
Nasdaq Comp	918.5	1.42	2.00	356.36
Mississippi	2705.3	11.59	1.66	3689.50
South Sea	263.6	2.02	2.92	840.71
Company				
Old East India	66.9	1.45	1.81	222.52
Company				
Tulips	76.2	918252.56	1.73	2269.66

Source: authors' own elaboration. **bubble index (BI); the current price has been taken as the maximum quotation or price. ***Data extracted from Table 1: basic data of the bubble sample analyzed. ****In CGAR, the minimum before the maximum has been used; the maximum and the elapsed days have been transformed to their equivalent in years.

frequency of intermediate values, serves to show bubble behavior. This explains the shape of the frequency/probability distribution, which demonstrates thicker tails, a sharper center, and a lower proportion of intermediate values between the peak and tails. In order to detect possible multicollinearity in the variables, we used the variance inflation factor (VIF) following Batrancea (2021a) and L. M. Batrancea (2021b). The VIF calculations can be found in the Appendix, as Table A.2. Of the results obtained, none of them exceeds the coefficient (1). This indicates that there is no correlation between the predictor variables and any other predictor variable in the model, and, therefore, there is an absence of multicollinearity. Regarding the possible heteroskedasticity and endogeneity of our variables, we have run Levene's test to verify the homogeneity of variances. The results obtained are shown in Table A.3 in the Appendix. The variances of the populations from which different samples are drawn are equal. Levene's test evaluates this assumption. The null hypothesis that the population variances of our study are equal is tested. If the P-value resulting from Levene's test is less than the 0.05 significance level, it is unlikely that the differences obtained in the sample variances were produced on the basis of random sampling from a population with equal variances. In our case, after running the test, all variables obtained a significance level of less than 0.05 for the cases of Bitcoin 2011 and Bitcoin 2013A. For the rest of the assumptions, all variances are constant within each cell. Levene's F-statistics cannot be calculated. Therefore, the null hypothesis of equality of variances is rejected, and it is concluded that there is a difference between variances in the population and that heteroscedasticity does not occur. Finally, Table A.4 in the Appendix shows the confidence intervals of the correlations between bubbles.

After applying the proposed methodology, the main results obtained are shown in Table 2.

The behavior of the so-called Bitcoin bubble in 2011 stands out especially, presenting the highest value by far. As for similar results, we observe how the Bitcoin bubble of the year 2021 A presents a very similar value to the Mississippi bubble (28.7 and 29.8, respectively) indicating a very similar bubble behavior. We also observe how the year 2021B Bitcoin bubble presents a very similar result to that obtained in the South Sea Company bubble (45.7 and 47.0, respectively), indicating a very similar bubble behavior.

Second, we examined the standard deviation (σ). In this sense, a larger standard deviation during a bubble would indicate that the asset price was more volatile during that bubble, suggesting that it was a larger or more significant bubble. In our case, we found the largest deviations in the 2021 A, B, and 2017 Bitcoin bubbles, followed by the Mississippi bubble. This suggests that Bitcoin bubble behavior in certain periods resembles the Mississippi bubble.

In the third column, we show the results derived from the application of the compound annual growth rate (CGAR) of prices during a specific period of time. This allows us to compare the behavior of the bubbles in the period considered. As we can see, according to this measure, there has not been another bubble similar to the tulip bubble, with a very high CGAR given the short period of time. The rest of the bubbles present more "consistent" values. The highest values, excluding the previous bubble, are the Bitcoin bubbles which, according to this criterion, do not present a behavior similar to other previous bubbles (although, possibly, their behavior is similar to that of the tulip bubble).

In the fourth column, we observe the results derived from applying the bubble index method. The 2021 A Bitcoin bubble obtains a result of 1.76, very close to the Mississippi bubble (1.66) and the tulip bubble (1.73), indicating very similar bubble behavior. In turn, the 2021B Bitcoin bubble (1.51) bears some proximity to the Mississippi bubble (1.66). The 2013B Bitcoin bubble (2.66), bears some proximity to the South Sea Company bubble (2.92). This indicates very similar bubble behavior.

The fifth column shows the results derived from the application of bubble size, measured as a percentage. The Bitcoin bubbles obtain the highest results in terms of percentage increase in asset prices from the start of the bubble to its peak. These Bitcoin bubbles are related to the Mississippi and tulip bubbles, and, to a lesser extent, to the South Sea Company bubble.

On the other hand, by applying the statistical technique of correlation, the following table has been generated (Table 3). This method has been used by several authors such as L. M. Batrancea (2021a) or Fairchild et al. (2022). This table in the form of a matrix shows the results of comparing each of the bubbles with the rest, marking the strongest relationships between Bitcoin bubbles and the rest Fairchild et al. (2022). This will allow us to complement the previous analysis.

Table 3 shows how, of the six Bitcoin bubbles analyzed, all but the one relating to 2011 have very similar behavior to that of the tulip bubble, with correlation values ranging from 0.370 to 0.507. The strongest relationship was between the tulip bubble and the 2017 Bitcoin bubble. We can also observe how the 2013A and 2021 A and B Bitcoin bubbles demonstrate a very similar behavior to that of the Mississippi bubble, with correlation values ranging between 0.108 and 0.805. The strongest relationship is between the Mississippi bubble and the 2021 A Bitcoin bubble. Relationships are found in three of the six Bitcoin bubbles and the Mississippi bubble.

The 2021 A and 2021B Bitcoin bubbles are related to the Nasdaq composite bubble behavior (dotcom bubble) with high values (0.775 and 0.564), respectively. A very strong relationship is also observed between the 2017 Bitcoin bubble and the DJIA bubble, with a score of 0.889. Although it is outside the scope of our study, we also observed how there is a strong relationship between the Mississippi bubble and the tulip bubble (a correlation of 0.907).

Discussion of results

The objective of this research was to find similarities between the behavior of Bitcoin cryptocurrency prices and the rest of the most important financial bubbles in economic history. We started by

Table 3 Correlations between the different Bitcoin bubbles and the rest of the bubbles.

		BTC 2011	BTC 2013A	BTC 2013B	BTC 2017	BTC 2021A	BTC 2021B	DJIA	Nasdaq Comp	Mississippi	South Sea Company	Old East India Company	Tulip
BTC 2011	Pearson's correlation		-.804**	0,052	-.302**	,214**	,538**	,363**	-.277**	-.469**	-.455**	-.239**	-0,561
	Sig. (bilateral)		0,000	0,363	0,000	0,000	0,000	0,007	0,000	0,000	0,000	0,000	0,073
BTC 2013A	Pearson's correlation	-.804**		0,047	,573**	-.856**	-.554**	-.331*	-.882**	0,188	-.663**	-.758**	0,402
	Sig. (bilateral)	0,000		0,496	0,000	0,000	0,000	0,014	0,000	0,602	0,000	0,000	0,220
BTC 2013B	Pearson's correlation	0,052	0,047		,208**	-.535**	-.526**	-.812**	-.299**	-.809**	-.603**	-.623**	0,418
	Sig. (bilateral)	0,363	0,496		0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,201
BTC 2017	Pearson's correlation	-.302**	,573**	,208**		-.827**	-.706**	,889**	-.742**	-.570*	-.526**	-.584**	0,507
	Sig. (bilateral)	0,000	0,000	0,000		0,000	0,000	0,000	0,000	0,027	0,000	0,000	0,111
BTC 2021A	Pearson's correlation	,214**	-.856**	-.535**	-.827**		,726**	-.827**	,775**	,805**	,824**	,853**	0,370
	Sig. (bilateral)	0,000	0,000	0,000	0,000		0,000	0,000	0,000	0,000	0,000	0,000	0,263
BTC 2021B	Pearson's correlation	,538**	-.554**	-.526**	-.706**	,726**		-.854**	,564**	0,109	0,000	-0,016	0,397
	Sig. (bilateral)	0,000	0,000	0,000	0,000	0,000		0,000	0,000	0,647	0,999	0,789	0,226
DJIA	Pearson's correlation	,363**	-.331*	-.812**	,889**	-.827**	-.854**		-.856**	0,605	-0,185	,314*	-0,049
	Sig. (bilateral)	0,007	0,014	0,000	0,000	0,000	0,000		0,000	0,203	0,223	0,036	0,886
Nasdaq Comp	Pearson's correlation	-.277**	-.882**	-.299**	-.742**	,775**	,564**	-.856**		,607**	,345**	-0,025	-0,172
	Sig. (bilateral)	0,000	0,000	0,000	0,000	0,000	0,000	0,000		0,000	0,000	0,605	0,613
Mississippi	Pearson's correlation	-.469**	0,188	-.809**	-.570*	,805**	0,109	0,605	,607**		-.561**	-.703**	0,907
	Sig. (bilateral)	0,000	0,602	0,000	0,027	0,000	0,647	0,203	0,000		0,000	0,000	0,277
South Sea Company	Pearson's correlation	-.455**	-.663**	-.603**	-.526**	,824**	0,000	-0,185	,345**	-.561**		,957**	-0,032
	Sig. (bilateral)	0,000	0,000	0,000	0,000	0,000	0,999	0,223	0,000	0,000		0,000	0,934
Old East India Company	Pearson's correlation	-.239**	-.758**	-.623**	-.584**	,853**	-0,016	,314*	-0,025	-.703**	,957**		-0,048
	Sig. (bilateral)	0,000	0,000	0,000	0,000	0,000	0,789	0,036	0,605	0,000	0,000		0,903
Tulip	Pearson's correlation	-0,561	0,402	0,418	0,507	0,370	0,397	-0,049	-0,172	0,907	-0,032	-0,048	
	Sig. (bilateral)	0,073	0,220	0,201	0,111	0,263	0,226	0,886	0,613	0,277	0,934	0,903	

Source: authors' own elaboration based on data extracted from (Investing.com, 2023), (Dow, 2023), (Frehen et al., 2013), (Thompson, 2006), and SPSS v.28.

asking two research questions: “Does the price of Bitcoin show a similar trend to that observed in previous financial bubbles?” and “What did authorities and regulators do after the historical bubbles were analyzed, and can we apply these formulas or actions to Bitcoin to prevent future bubbles?” To answer both questions, a research approach was adopted based on the search for similarities between the behavior of Bitcoin and that of previous speculative bubbles. Actions taken in previous financial bubbles with similarities in behavior to Bitcoin were also identified.

The first thing to note is the difficulty in comparing bubbles that have occurred at different historical moments. Comparing bubbles is not a simple task, because the historical conditions (applicable to the historical bubbles under study) and current conditions (applied to the study of Bitcoin bubbles) are different, so the bubbles, their behavior, duration, and size are highly variable. However, there are some studies that, despite the difficulties, have made this comparison, such as those by Fairchild et al. (2022) and Xu (2023), who used the dot com bubble in the 2000s and compared it with Bitcoin. Other authors, such as Phillips et al. (2013), while not conducting research on cryptocurrencies, adopted a similar approach to examine the evolution of the price of a financial asset compared to the behavior of other assets in previous bubbles. On the other hand, Bitcoin was adopted in this study as a representative currency of the cryptocurrency market, as other authors, such as Fabris and Ješić (2023), have recently done. It is the leading cryptocurrency and possesses the highest market capitalization. Bitcoin bubbles that occurred in the 2013 and 2023 periods have been analyzed and have been widely identified in the literature by Kyriazis et al. (2020) and Gautam et al. (2023), among others. Furthermore, cryptocurrencies, represented by Bitcoin in this study, are extremely volatile, as shown by Kerr et al. (2023), a characteristic that they share with other previously analyzed bubbles.

The results obtained in this research reveal that the six Bitcoin bubbles analyzed (all except the one relating to 2011) demonstrate a very similar behavior to the tulip bubble. In addition, the Bitcoin bubbles of 2013A and of 2021 A and B present a very similar behavior to the Mississippi bubble. The strongest relationship is between the Mississippi bubble and the 2021 Bitcoin bubble. The fact that Bitcoin is closely related to these episodes was certainly to be expected since several previous studies indicate that its use and massive adoption have occurred in response to speculative intentions, as shown by Alonso et al. (2023), Auer and Tercero-Lucas (2022), and Milka (2021), and not to its use as a currency. Exactly the same happened, at the time, with the tulip bubble, as shown by French (2014) and Kindleberger (2016). The price of the common bulb increased more than 25 times in January 1637 and then collapsed in February of that year, according to French (2014). In other words, there was irrational purchase and adoption based on speculation. However, other authors, such as Garber (1989), consider that only the final phase of this speculative process can be understood as a bubble. In the case of the Mississippi bubble, in a short time, the company was well received by the French public (Nguyen, 2018). As a result of all this, the stock went from 150 to 500 *livres de tournois* between 1717 and May 1719 and from 500 to 10,000 *livres de tournois* from June 1719 to January 1720. Doubts about the company's profitability and the Royal Bank's liquidity problems resulted in a bursting of this price bubble during 1720 (Bruner and Miller, 2018; Paul, 2020). In this case, the behavior was very similar to that for Bitcoin, where, many times, people invested simply out of confidence in the technology, as argued by Balutel et al. (2023), or as a means of speculation, due to its high growth potential and the volatility of returns, according to Vasudeva (2023), or for short-term gains, as described by Zhang et al. (2021). However,

when negative rumors spread, the price drops considerably, especially affecting younger people, as indicated by Król and Zdonek (2022), and some authors even speak of similarity with “gambling games”, such as Johnson et al. (2023). A similar effect to the one described above was found by Demir et al. (2022) in their study on the behavior of fan tokens; in this case, the influence on the price was due to the victories or defeats of the soccer teams represented by the tokens. However, Bitcoin has partially recovered from major falls and is still an asset that is present in the market, according to Gniadkowska-Szymańska et al. (2022). Our study compares the durations of the bubbles in terms of days. We find significantly longer bubble durations for Bitcoin than Assaf et al. (2024) found in their study on fan tokens. They found that the duration of the bubble period is between 0 and 5% of the time period studied; “bubbles in fan tokens are much shorter, lasting only a few days”. In addition, Bitcoin bubbles show significantly larger price increases and steeper price drops compared to bubbles in fan token prices. Podhorsky (2024)'s study points out that Bitcoin's volatile and explosive price trajectory is a consequence of the Bitcoin protocol's supply management system and expectations, and that Bitcoin's apparent price bubbles can be attributed to its non-stationary market fundamentals. This is consistent with the situation experienced with the tulip bubble and Mississippi bubble. Our study has shown that Bitcoin bubble periods are highly correlated with these two. In the case of Bitcoin beyond expectations, Bazán-Palomino (2021) and M'bakob (2024) point out that market volatility is the strongest in the first two months after the occurrence of a fork and drops thereafter. This same behavior was observed in our study and is reflected in Table 1. Petti and Sergio (2024) found that banking crises affect the price of Bitcoin. In our study, we found a similar result when keeping the similarities between the behavior of Bitcoin in certain periods as a bubble, with the Mississippi bubble (which is of financial origin). For all these reasons, and with the results obtained, we can conclude that the periods in which Bitcoin has behaved as a bubble bear a strong relationship and similarity with two historical bubbles: the Mississippi bubble and the tulip bubble. These results are aligned with those obtained in other previous studies such as Taskinsoy (2019) or Ha and Lee (2020).

Having identified the previous financial bubbles with which Bitcoin has certain parallels, they can be extracted, as a recommendation for states and international organizations, to try to replicate the actions undertaken after these two bubbles. In the case of the Mississippi bubble, the French state harshly enforced legislation, producing a wave of convictions against investors suspected of having obtained illegal profits through the state assuming the astronomical debt of the former company. After the tulip bubble, a committee dedicated to the fulfillment of outstanding payments, known as “*Commissarissen van de Bloemen Saecken*” (Commissioners of Floral Affairs) of Haarlem, was created. After financial crises, regulation of the banking sector tends to increase, as shown by the successive Basel I, II and III standards, which raise the capital requirements of financial institutions in order to strengthen their solvency.

In the case of decentralized cryptocurrencies, it is not possible to completely prevent the appearance of bubbles, because their issuance does not depend on governments or central banks, but it is possible to regulate their use through exchanges, avoid user fraud, and reduce the environmental cost of mining these assets, as described by Dale (2016); Podhorsky (2024); Paul (2020); Shanaev et al. (2020); Fletcher et al. (2021); Sanz-Bas et al. (2021); and Nández Alonso et al. (2021). There have been some exchange bankruptcies in recent years, such as that of FTX, due to fraud, as described by Bouri et al. (2023), and the SEC has imposed fines on Binance, the largest intermediary of these crypto assets. This has caused, together with

the bankruptcy of the TerraUSD stablecoin, a greater distrust among investors for these digital assets, although there are many differences between them, as described by Jorcano et al. (2024). This market is not currently regulated, but in the European Union (EU), the MiCA Act has been approved, as described by Bočánek (2021); this act regulates exchanges operating in the EU and establishes certain requirements for the providers of these digital services. This is the first international legislation on cryptocurrencies and may guide other countries to adopt similar measures. The law aims to combat money laundering and protect users from scams. On the other hand, in the US, the Securities and Exchange Commission (SEC) has approved the creation of Bitcoin Exchange Traded Funds (ETFs), which will help reduce the risk of trading these digital assets for many clients. In addition, in April 2024, Hong Kong approved a Bitcoin ETF Sopt. The announcement of this move boosted the price of the cryptocurrency, which had fallen days earlier due to the conflict in the Middle East. It is also possible that the price of Bitcoin will gradually stabilize without the need for regulation alone. The reason for this is explored by Grobys (2024), when he points out that, as time progresses and the reward for Bitcoin miners becomes lower, there may be less of a bubble effect. Governments and central banks could regulate some aspects of this market by considering the creation of their own centralized digital currencies, known as CBDCs, as described by Alonso (2023); Nández Alonso et al. (2020); Nández Alonso et al. (2021); Echarte Fernández et al. (2021); and Xia et al. (2023). Although some studies show that the general sentiment of the population towards these new central digital currencies is positive, there is also some resistance to their use in some sectors of the population, as described by Ozili and Nández Alonso (2024).

As limitations of our research, we can point out the following. Firstly, it is very difficult to make a comparison with Bitcoin. It is a cryptocurrency that is still in operation, so the periods of bubble behavior analyzed could be surpassed by later periods, and it has different characteristics from shares. Another limitation of the study is whether the results obtained from the comparison with Bitcoin can be extrapolated to other cryptocurrencies. Although all of them have a certain relationship with Bitcoin in their behavior (price or exchange rate with respect to the dollar), it is possible that there are divergences in their behavior that differ from the results obtained in this study. It should also be noted as a limitation that we are comparing bubbles that have been generated in different historical periods, with very different origins and causes, although the objective is to measure the degree of similarity in terms of the behavior of the bubble and, once the similarities between them have been detected, to analyze the measures adopted after the bubble burst. All this is carried out in order to evaluate whether these measures could be replicated with Bitcoin today. This has been extensively developed in the introductory and literature review section. The final limitation to note is that we have selected a sample of bubbles to compare with the periods of Bitcoin bubble behavior, but we have left out others, such as real estate bubbles; this could affect the outcome of our study. Looking to the future, a line of research to follow would be to expand the base of bubbles by adding other representative bubbles in the world of cryptocurrencies such as Ether, Ripple, or Cardano, as they are currently among the 10 cryptocurrencies with the highest capitalization (Coinmarketcap, 2023).

Conclusions

The objective of this research was to carry out a comparative analysis between the evolution of the Bitcoin price and the behavior of other preceding financial bubbles. The five most relevant speculative bubbles in history were analyzed in detail: tulip mania (1634–1637), the Mississippi company bubble (1719–1720), the South Sea company bubble (1720), the New York Stock Exchange crash of 1929, and the dotcom bubble

(1997–2001). The starting hypothesis was that there must be parallels between Bitcoin prices and those of other speculative assets. After the empirical study, the hypothesis was confirmed. This research shows that there are significant coincidences between the behavior of Bitcoin prices and that of selected previous bubbles.

The first conclusion that can be drawn from this study is that it is difficult to make a comparison between the different bubbles that have occurred throughout history. This is because the economic, social, technological, and legal conditions surrounding and influencing the bubbles are different. As a result, bubbles, and their behavior, duration, and size are highly variable.

Looking at the length of days from the trough to the peak, the Bitcoin bubbles of 2021 and those of 2013 are similar to the tulip bubble. In fact, if we compare the days from peak to trough after the bubble burst, all Bitcoin bubbles bear a relationship to the tulip bubble. This is particularly true of the first Bitcoin bubble of 2021, which lasted 85 days, and of the tulip bubble, which lasted 87 days. If we compare the percentage growth from the minimum to the maximum, we also observe how the values of the Bitcoin bubbles (especially those of 2011, 2013, and 2017) demonstrate a great similarity with the tulip bubble and the Mississippi bubble.

As far as the standard deviation (σ) comparison is concerned, the largest deviations are found in the 2021 and 2017 Bitcoin bubbles followed by the Mississippi bubble. This suggests that the Bitcoin bubble behavior in those periods resembles the Mississippi bubble. When we apply the bubble index, the initial 2021 Bitcoin bubble scores very close to the Mississippi bubble and the tulip bubble, indicating very similar bubble behavior. In turn, the second Bitcoin bubble of 2021 bears some proximity to the Mississippi bubble. The second Bitcoin bubble of 2013 bears some proximity to the South Seas company bubble. This indicates very similar bubble behavior. In terms of the bubble size criterion, measured in percentage, Bitcoin bubbles score the highest in terms of percentage increase in asset prices from the start of the bubble to its peak. These Bitcoin bubbles are related to the Mississippi and tulip bubbles and, to a lesser extent, to the South Sea Company bubble.

Regarding the statistical analysis of correlations, the results suggest that, of the six Bitcoin bubbles analyzed, all except the one related to 2011 demonstrated very similar behavior to that of the tulip bubble. In addition, the 2013A and 2021A and B Bitcoin bubbles demonstrated similar behavior to that of the Mississippi bubble. The strongest relationship was between the Mississippi bubble and the 2021A Bitcoin bubble.

Therefore, we can conclude that the periods in which Bitcoin has behaved like a bubble are closely related and similar to two historical bubbles: the Mississippi bubble and the tulip bubble. Thus, we can state that there is sufficient empirical evidence to support the hypothesis that Bitcoin does indeed demonstrate bubbly behavior.

The research acknowledges limitations such as omitting significant economic bubbles like the 2008 real estate crisis and the challenge of comparing disparate economic processes over time. However, it offers valuable insights for empirical researchers and Bitcoin investors, informing policymakers on cryptocurrency regulation and risk assessment. Recommendations include emulating actions taken after the 2008 crisis and highlighting the potential benefits of regulations like the MiCA Act and the approval of Bitcoin ETFs in enhancing investor security. This study can be expanded in the future by considering the behavior of other cryptocurrencies and incorporating other speculative processes in economic history to draw further conclusions that can help to reduce the impact of speculative bubbles.

Data availability

All datasets are available in the following research repository:
<https://portalcientifico.ucavila.es/datos/658c64327ad95039d6d85b39>.

Received: 18 October 2023; Accepted: 22 May 2024;

Published online: 03 June 2024

References

- Aasen MR (2011) Applying Altman's Z-Score to the Financial Crisis: an empirical study of financial distress on Oslo Stock Exchange [Thesis, NHH Brage]. <http://hdl.handle.net/11250/169347>
- Adämmer P, Bohl MT (2015) Speculative bubbles in agricultural prices. *Q Rev Econ Financ* 55:67–76
- Agosto A, Cafferata A (2020) Financial bubbles: A study of co-explosivity in the cryptocurrency market. *Risks* 8(2):34. <https://doi.org/10.3390/risks8020034>
- Alonso SLN (2023) Can Central Bank Digital Currencies be green and sustainable? *Green Finance* 5(4):603–623. <https://doi.org/10.3934/gf.2023023>
- Alonso SLN, Jorge-Vázquez J, Rodríguez PA, Hernández BMS (2023) Gender gap in the ownership and use of cryptocurrencies: Empirical evidence from Spain. *J Open Innov: Technol, Mark, Complex* 9(3):100103. <https://doi.org/10.1016/j.joitmc.2023.100103>
- Altman EI, Kuehne BJ (2016) Credit market bubble building? A forming credit bubble could burst by 2017. *Quant Financ Lett* 4(1):14–18. <https://doi.org/10.1080/21649502.2015.1165962>
- Ammous S (2018) The bitcoin standard: The decentralized alternative to central banking. John Wiley & Sons
- Assaf A, Demir E, Ersan O (2024) Detecting and date-stamping bubbles in fan tokens. *Int Rev Econ Financ* 92:98–113. <https://doi.org/10.1016/j.iref.2024.01.039>
- Astill S, Harvey DI, Leybourne SJ, Taylor AMR (2017) Tests for an end-of-sample bubble in financial time series. *Econ Rev* 36(6–9):651–666. <https://doi.org/10.1080/07474938.2017.1307490>
- Auer R, Tercero-Lucas D (2022) Distrust or speculation? The socioeconomic drivers of U.S. cryptocurrency investments. *J Financial Stab* 62:101066. <https://doi.org/10.1016/j.jfs.2022.101066>
- Auer R, Cornelli G, Doerr S, Frost J, Gambacorta L (2022) Crypto trading and Bitcoin prices: evidence from a new database of retail adoption (pp. 1–28). Bank for International Settlements (BIS). <https://www.bis.org/publ/work1049.html>
- Balutel D, Felt M-H, Nicholls G, & Voia M-C (2023) Bitcoin awareness, ownership and use: 2016–20. *Appl Econ* 1–26. <https://doi.org/10.1080/00036846.2023.2166667>
- Batranea L (2021a) Empirical evidence regarding the impact of economic growth and inflation on economic sentiment and household consumption. *J Risk Financial Manag* 14(7):336. <https://doi.org/10.3390/rjfm14070336>
- Batranea LM (2021b) An econometric approach on performance, assets, and liabilities in a sample of banks from Europe, Israel, United States of America, and Canada. *Mathematics* 9(24):3178. <https://doi.org/10.3390/math9243178>
- Bazán-Palomino W (2021) How are Bitcoin forks related to Bitcoin? *Financ Res Lett* 40:101723. <https://doi.org/10.1016/j.frl.2020.101723>
- Bočánek M (2021) First draft of crypto-asset regulation (mica) with the European Union and potential implementation. *Financ Law Rev* 22(2):37–53. <https://doi.org/10.4467/22996834flr.21.011.13979>
- Bouri E, Gupta R, Roubaud D (2019) Herding behaviour in cryptocurrencies. *Financ Res Lett* 29:216–221. <https://doi.org/10.1016/j.frl.2018.07.008>
- Bouri E, Kamal E, Kinatader H (2023) FTX Collapse and systemic risk spillovers from FTX Token to major cryptocurrencies. *Financ Res Lett* 56:104099. <https://doi.org/10.1016/j.frl.2023.104099>
- Bovet A, Campajola C, Lazo JF, Mottes F, Pozzana I, Restocchi V, Saggese P, Vallarano N, Squartini T, Tessone CJ (2018, May 11). Network-based indicators of Bitcoin bubbles. *arXiv.Org*. <https://arxiv.org/abs/1805.04460>
- Bruner RF, Miller S (2018) 1720: John Law and the Mississippi bubble. *SSRN Electronic J*. <https://doi.org/10.2139/ssrn.3233299>
- Brunnermeier MK (2016) bubbles. In *Banking Crises* (pp. 28–36). Palgrave Macmillan UK. https://doi.org/10.1057/9781137553799_5
- Buterin D, Janković S, Klaus S (2020) Cryptocurrencies, bitcoin and market bubbles. *Smart Governments, Regions and Cities*, 303
- Caferra R, Tedeschi G, Morone A (2021) Bitcoin: Bubble that bursts or Gold that glitters? *Econ Lett* 205:109942. <https://doi.org/10.1016/j.econlet.2021.109942>
- Caginalp G, Porter D, Smith V (2001) Financial bubbles: Excess cash, momentum, and incomplete information. *J Psychol Financ Mark* 2(2):80–99. https://doi.org/10.1207/s15327760jpfm0202_03
- Cagli EC (2019) Explosive behavior in the prices of Bitcoin and altcoins. *Financ Res Lett* 29:398–403. <https://doi.org/10.1016/j.frl.2018.09.007>
- Cheah E-T, Fry J (2015) Speculative bubbles in Bitcoin markets? An empirical investigation into the fundamental value of Bitcoin. *Econ Lett* 130:32–36. <https://doi.org/10.1016/j.econlet.2015.02.029>
- Cheung A, Wai K, Roca E, Su J-J (2015) Crypto-currency bubbles: An application of the Phillips–Shi–Yu (2013) methodology on Mt. Gox bitcoin prices. *Appl Econ* 47(23):2348–2358. <https://doi.org/10.1080/00036846.2015.1005827>
- Ciaian P, Rajcaniova M, Kancs d'Artis (2015) The economics of BitCoin price formation. *Appl Econ* 48(19):1799–1815. <https://doi.org/10.1080/00036846.2015.1109038>
- Coinmarketcap (2023, June 27) Cryptocurrency prices, charts and market capitalizations. CoinMarketCap. <https://coinmarketcap.com/es/>
- Corbet S, Lucey BM, Yarovaya L (2017) Datestamping the bitcoin and ethereum bubbles. *SSRN Electronic J* <https://doi.org/10.2139/ssrn.3079712>
- Cretarola A, Figà-Talamanca G (2020) Bubble regime identification in an attention-based model for Bitcoin and Ethereum price dynamics. *Econ Lett* 191:108831. <https://doi.org/10.1016/j.econlet.2019.108831>
- Cross JL, Hou C, Trinh K (2021) Returns, volatility and the cryptocurrency bubble of 2017–18. *Econ Model* 104:105643
- Dąbrowski P (2021) Stock indices breakdown during the pandemic as the most dynamic bear market in history: Consequences for individual investors. *Risks* 10(1):1. <https://doi.org/10.3390/risks10010001>
- Dale RS, Johnson JE, Tang L (2005) Financial markets can go mad: evidence of irrational behavior during the South Sea Bubble 1. *Econ Hist Rev* 58(2):233–271
- Dale R (2016) The first crash: Lessons from the South Sea bubble. Princeton University Press
- DeLong JB, Magin K (2006) A short note on the size of the dot-com bubble. National Bureau of Economic Research. <https://doi.org/10.3386/w12011>
- Demir E, Ersan O, Popesko B (2022) Are fan tokens fan tokens? *Financ Res Lett* 47:102736. <https://doi.org/10.1016/j.frl.2022.102736>
- Demmler M, Fernández Domínguez AO (2021) Bitcoin and the South Sea Company: A comparative analysis. *Revista Finanzas y Política Económica*, 13(1). <https://doi.org/10.14718/revfinanzpolitecon.v13.n1.2021.9>
- Dow J (2023) Dow Jones Industrial Average 1928–1930. https://www.spglobal.com/spdji/en/web-data-downloads/reports/dja-performance-report-monthly.xls?force_download=true
- Dreger C, Zhang Y (2013) Is there a bubble in the Chinese housing market? *Urban Policy Res* 31(1):27–39
- Echarte Fernández MÁ, Nánéz Alonso SL, Jorge-Vázquez J, Reier Forradellas RF (2021) Central banks' monetary policy in the face of the COVID-19 economic crisis: Monetary stimulus and the emergence of cbdc. *Sustainability* 13(8):4242. <https://doi.org/10.3390/su13084242>
- Echarte Fernández MA, Nánéz Alonso SL, Reier Forradellas R, Jorge-Vázquez J (2022) From the Great Recession to the COVID-19 Pandemic: The Risk of Expansionary Monetary Policies. *Risks*. <https://doi.org/10.3390/risks10020023>
- Enoksen FA, Landsnes ChJ, Lučivjanská K, Molnár P (2020) Understanding risk of bubbles in cryptocurrencies. *J Econ Behav Organ* 176:129–144. <https://doi.org/10.1016/j.jebo.2020.05.005>
- Fabris N, Ješić M (2023) Are gold and bitcoin a safe haven for European indices? *J Cent Bank Theory Pr* 12(1):27–44. <https://doi.org/10.2478/jcbtp-2023-0002>
- Fairchild RJ, Kinsella J, Hinvest N, He C, Crypto Investors' Behaviour and Performance and the Dot-Com Bubble Compared: This Time it is Different? (November 1, 2022). Available at SSRN: <https://ssrn.com/abstract=4280504> or <https://doi.org/10.2139/ssrn.4280504>
- Finder. (2023, DECEMBER 2). Finder cryptocurrency adoption index", Finder. <https://www.finder.com/finder-cryptocurrency-adoption-index>
- Fletcher E, Larkin C, Corbet S (2021) Countering money laundering and terrorist financing: A case for bitcoin regulation. *Res Int Bus Financ* 56:101387. <https://doi.org/10.1016/j.ribaf.2021.101387>
- Frehen RGP, Goetzmann WN, Geert Rouwenhorst K (2013) New evidence on the first financial bubble. *J Financ Econ* 108(3):585–607. <https://doi.org/10.1016/j.jfineco.2012.12.008>
- French D (2014) The first speculative bubbles. Union Editorial
- Fruehwirt W, Hochfilzer L, Weydemann L, Roberts S (2021) Cumulation, crash, coherence: A cryptocurrency bubble wavelet analysis. *Financ Res Lett* 40:101668. <https://doi.org/10.1016/j.frl.2020.101668>
- Fry J, Cheah E-T (2016) Negative bubbles and shocks in cryptocurrency markets. *Int Rev Financ Anal* 47:343–352. <https://doi.org/10.1016/j.irfa.2016.02.008>
- Furi T, Mulgeta W, Wolteji Chala B (2022) Determinants of financial instability in selected east and southern African countries. *Int J Econ, Financ Manag Sci* 10(2):37. <https://doi.org/10.11648/j.ijefm.20221002.11>
- Galbraith JK (2009) The Great Crash, 1929. Penguin
- Gandal N, Hamrick J, Moore T, Oberman T (2018) Price manipulation in the Bitcoin ecosystem. *J Monetary Econ* 95:86–96. <https://doi.org/10.1016/j.jmoneco.2017.12.004>

- Garber P (1989) Tulipmania. *J Polit Econ* 97, no. 3
- García D, Tessone CJ, Mavrodiev P, Perony N (2014) The digital traces of bubbles: Feedback cycles between socio-economic signals in the Bitcoin economy. *J R Soc Interface* 11(99):20140623. <https://doi.org/10.1098/rsif.2014.0623>
- García-Corral FJ, Cordero-García JA, de Pablo-Valenciano J, Uribe-Toril J (2022) A bibliometric review of cryptocurrencies: How have they grown? *Financ Innov* 8(1). <https://doi.org/10.1186/s40854-021-00306-5>
- Gautam V, Li W, Carter DA. Volatility Modeling Using High Frequency Data to Identify Cryptocurrency Bubbles (February 13, 2023). <https://doi.org/10.2139/ssrn.4357317>
- Gemici E, Polat M, Gök R, Khan MA, Khan MA, Kilic Y (2023) Do bubbles in the bitcoin market impact stock markets? Evidence from 10 major stock markets. *SAGE Open*, 13(2). <https://doi.org/10.1177/21582440231178666>
- Geuder J, Kinatender H, Wagner NF (2019) Cryptocurrencies as financial bubbles: The case of Bitcoin. *Financ Res Lett* 31. <https://doi.org/10.1016/j.frl.2018.11.011>
- Gniadkowska-Szymańska A, Olgić Draženović B, Suljić Nikolaj S (2022) Selected cryptocurrency returns and capital gains tax - Based on the example of countries with varying degrees of legal regulations concerning cryptocurrencies. *Finans i Prawo Finans* 3(35):53–64. <https://doi.org/10.18778/2391-6478.3.35.04>
- Goldgar A (2008) Tulipmania: Money, honor, and knowledge in the Dutch golden age. University of Chicago Press
- Goodnight GT, Green S (2010) Rhetoric, risk, and markets: The dot-com bubble. *Q J Speech* 96(2):115–140. <https://doi.org/10.1080/00335631003796669>
- Grobys K (2024) No reward—no effort: Will Bitcoin collapse near to the year 2140? *Financ Res Lett* 63:105294. <https://doi.org/10.1016/j.frl.2024.105294>
- Gronwald M (2021) How explosive are cryptocurrency prices? *Financ Res Lett* 38:101603. <https://doi.org/10.1016/j.frl.2020.101603>
- Ha T, Lee S (2020) Examination of bitcoin exchange through agent-based modeling: Focusing on the perceived fundamental of bitcoin. *IEEE Trans Eng Manag* 69(4):1294–1307. <https://doi.org/10.1109/TEM.2020.2983416>
- Harsha S, Ismail B (2019) Review on financial bubbles. *Stat J IAOS* 35(3):501–510. <https://doi.org/10.3233/sji-180476>
- Hommes C, Sonnemans J, Tuinstra J, van de Velden H (2008) Expectations and bubbles in asset pricing experiments. *J Econ Behav Organ* 67(1):116–133. <https://doi.org/10.1016/j.jebo.2007.06.006>
- Holub M, Johnson J (2019) The impact of the Bitcoin bubble of 2017 on Bitcoin's P2P market. *Financ Res Lett* 29:357–362
- Huber TA, Sornette D (2022) Boom, bust, and bitcoin: bitcoin-bubbles as innovation accelerators. *J Econ Issues* 56(1):113–136
- Investing.com (2023, January 18). Bitcoin historical data. Investing.Com. <https://www.investing.com/crypto/bitcoin/historical-data>
- Irwin SH, Sanders DR, Merrin RP (2009) Devil or angel? The role of speculation in the recent commodity price boom (and bust). *J Agric Appl Econ* 41(2):377–391
- Irwin SH, Sanders DR (2011) Index funds, financialization, and commodity futures markets. *Appl Econ Perspect Policy* 33(1):1–31
- Ji H, Zhang H (2023) Application of the LPPL model in the identification and measurement of structural bubbles in the Chinese stock market. *North Am J Econ Financ* 70:102060. <https://doi.org/10.1016/j.najef.2023.102060>
- Johannessen J-A (2016) The South Sea and Mississippi bubbles of 1720. In *Innovations Lead to Economic Crises* (pp. 59–87). Springer International Publishing. https://doi.org/10.1007/978-3-319-41793-6_4
- Johansen A, Ledoit O, Sornette D (2000) Crashes as Critical Points. *Int J Theor Appl Financ* 03(02):219–255. <https://doi.org/10.1142/s0219024900000115>
- Johnson B, Co S, Sun T, Lim CCW, Stjepanović D, Leung J, Saunders JB, Chan GCK (2023) Cryptocurrency trading and its associations with gambling and mental health: A scoping review. *Addictive Behav* 136:107504. <https://doi.org/10.1016/j.addbeh.2022.107504>
- Jorcano J, Echarte MÁ, Náñez Alonso SL (2024) The asset-backing risk of stablecoin trading: The case of Tether. *Econ Business Rev* 10(1). <https://doi.org/10.18559/ebrev.2024.1.1211>
- Kanojia S, Malhotra D (2021) A case study of stock market bubbles in the Indian stock market. *Indian J Financ* 15(2):22. <https://doi.org/10.17010/ijfi/2021/v15i2/157638>
- Kasman A, Carvallo O (2014) Financial stability, competition and efficiency in Latin American and Caribbean banking. *J Appl Econ* 17(2):301–324. [https://doi.org/10.1016/s1514-0326\(14\)60014-3](https://doi.org/10.1016/s1514-0326(14)60014-3)
- Kerr DS, Loveland KA, Smith KT, Smith LM (2023) Cryptocurrency risks, fraud cases, and financial performance. *Risks* 11(3):51. <https://doi.org/10.3390/risks11030051>
- Kenett DY, Preis T, Gur-Gershgoren G, Ben-Jacob E (2012) Quantifying meta-correlations in financial markets. *EPL (Europhys Lett)* 99(3):38001. <https://doi.org/10.1209/0295-5075/99/38001>
- Kindleberger C (1987) Bubbles. The New Palgrave: A Dictionary of Economics, J Eatwell, M Milgate and P Newman. New York: The Stockton Press
- Kindleberger C (2016) Manias, panics and crashes: A history of financial crises. Springer
- Kreuser JL, Sornette D (2018) Bitcoin bubble trouble. *Forthcoming in Wilmott Magazine*, 18–24
- Król K, Zdonek D (2022) Digital assets in the eyes of generation Z: Perceptions, outlooks, concerns. *J Risk Financ Manag* 16(1):22. <https://doi.org/10.3390/jrfm16010022>
- Kyriazis N, Papadamou S, Corbet S (2020) A systematic review of the bubble dynamics of cryptocurrency prices. *Res Int Bus Financ* 54:101254. <https://doi.org/10.1016/j.ribaf.2020.101254>
- Lee N-K, Yi E, Ahn K (2020) Boost and burst: Bubbles in the bitcoin market. In *Lecture Notes in Computer Science* (pp. 422–431). Springer International Publishing. https://doi.org/10.1007/978-3-030-50371-0_31
- Łęt B, Sobański K, Świder W, Włosik K (2023) What drives the popularity of stablecoins? Measuring the frequency dynamics of connectedness between volatile and stable cryptocurrencies. *Technol Forecast Soc Change* 189:122318. <https://doi.org/10.1016/j.techfore.2023.122318>
- Łęt B, Sobański K, Świder W, Włosik K (2022) Is the cryptocurrency market efficient? Evidence from an analysis of fundamental factors for Bitcoin and Ethereum. *Int J Manag Econ* 58(4):351–370. <https://doi.org/10.2478/ijme-2022-0030>
- Leath JL (2019) Is Bitcoin Reminiscent of Past Bubbles? Honors Theses, Link <https://scholar.utc.edu/cgi/viewcontent.cgi?article=1206&context=honors-theses>
- Li ZZ, Tao R, Su CW et al. (2019) Does bitcoin bubble burst? *Qual Quant* 53:91–105. <https://doi.org/10.1007/s11335-018-0728-3>
- Li Y, Wang Z, Wang H, Wu M, Xie L (2021) Identifying price bubble periods in the Bitcoin market-based on GSADF model. *Qual Quant* 55(5):1829–1844. <https://doi.org/10.1007/s11335-020-01077-4>
- Li Y, Zhang W, Urquhart A, Wang P (2022) The role of media coverage in the bubble formation: Evidence from the Bitcoin market. *J Int Financ Mark, Inst Money* 80:101629. <https://doi.org/10.1016/j.intfin.2022.101629>
- Lucey BM, O'Connor FA (2013) Do bubbles occur in the gold price? An investigation of gold lease rates and Markov Switching models. *Borsa Istanbul Rev* 13(3):53–63
- M'bakob GB (2024) Bubbles in Bitcoin and Ethereum: The role of halving in the formation of super cycles. *Sustain Futures* 7:100178. <https://doi.org/10.1016/j.sfsr.2024.100178>
- McDonald IV MB (2022) The shrinking stock market. *J Financ Mark* 58:100664. <https://doi.org/10.1016/j.finmar.2021.100664>
- Miao J, Shen Z, Wang P (2019) Monetary policy and rational asset price bubbles: Comment. *Am Econ Rev* 109(5):1969–1990. <https://doi.org/10.1257/aer.20180145>
- Miffre J, Brooks C (2013) Do long-short speculators destabilize commodity futures markets? *Int Rev Financ Anal* 30:230–240
- Milka P (2021) Speculation in the cryptocurrency market. *Rev Econ, Financ Invest* 1(1). <https://doi.org/10.53752/refi.2020.1.12>
- Morris JJ, Alam P (2008) Analysis of the dot-com bubble of the 1990s. *SSRN Electronic J*. <https://doi.org/10.2139/ssrn.1152412>
- Náñez Alonso SL, Echarte Fernández MÁ, Sanz Bas D, Kaczmarek J (2020) Reasons fostering or discouraging the implementation of central bank-backed digital currency: A review. *Economies* 8(2):41. <https://doi.org/10.3390/economies8020041>
- Náñez Alonso SL, Jorge-Vázquez J, Echarte Fernández MÁ, Reier Forradellas RF (2021) Cryptocurrency mining from an economic and environmental perspective. Analysis of the most and least sustainable countries. *Energies* 14(14):4254. <https://doi.org/10.3390/en14144254>
- Náñez Alonso SL, Jorge-Vázquez J, Reier Forradellas RF (2021) Central banks digital currency: Detection of optimal countries for the implementation of a CBDC and the implication for payment industry open innovation. *J Open Innov: Technol, Mark, Complex* 7(1):72. <https://doi.org/10.3390/joitmc7010072>
- Náñez Alonso SL, Echarte Fernández MÁ, Sanz Bas D, Pérez Rico C (2024) El Salvador: An analysis of the monetary integration law and the bitcoin law. *Braz J Political Econ* 44(1):189–209. <https://doi.org/10.1590/0101-31572024-3459>
- Ncube A, Neuhaus T (2023) Is Bitcoin the black Tulip of the 21st Century? *Int J Econ Financ Stud* 15(2):231–245. <https://doi.org/10.34109/ijefs2023151212>
- Nguyen J (2018) Building on credit: Architecture and the Mississippi bubble (1716–1720). *Grey Room* 71:40–67. https://doi.org/10.1162/grey_a_00241
- Noussair CN, Tucker S (2016) Cash inflows and bubbles in asset markets with constant fundamental values. *VALUES. Econ Inq* 54(3):1596–1606. <https://doi.org/10.1111/ecin.12320>
- Obayashi Y, Protter P, Yang S (2015) The lifetime of a financial bubble. *SSRN Electronic J*. <https://doi.org/10.2139/ssrn.2618486>
- Östensson O (2012) The 2008 commodity price boom: did speculation play a role? *Min Econ* 25(1):17–28

- Ozili PK, Nañez Alonso SL (2024) Central bank digital currency adoption challenges, solutions, and a sentiment analysis. *J Central Bank Theory Pract* 13(1). <https://sciendo.com/es/journal/JCBTP?tab=ediciones>
- Paul HJ (2020) John Law, the South Sea bubble, and Dutch satire. In *Comedy and Crisis* (pp. 103–118). Liverpool University Press. <https://doi.org/10.3828/liverpool/9781789622201.003.0005>
- Petti D, Sergio I (2024) Bank crisis boosts bitcoin price. *J Risk Financ Manag* 17(4):134. <https://doi.org/10.3390/jrfm17040134>
- Phillips PCB, Shi SP, Yu J (2013) Testing for multiple bubbles: Historical episodes of exuberance and collapse in the S&P 500. *SSRN Electronic J*. <https://doi.org/10.2139/ssrn.2327609>
- Podhorsky A (2024) Bursting the bitcoin bubble: Do market prices reflect fundamental bitcoin value? *Int Rev Financ Anal* 93:103158. <https://doi.org/10.1016/j.irfa.2024.103158>
- Porter DP, Smith VL (1994) Stock market bubbles in the laboratory. *Appl Math Financ* 1(2):111–128. <https://doi.org/10.1080/13504869400000008>
- Preis T, Stanley HE (2011) Bubble trouble. *Phys World* 24(05):29–32. <https://doi.org/10.1088/2058-7058/24/05/34>
- Ranganathan S, Kivelä M, Kanninen J (2018) Dynamics of investor spanning trees around dot-com bubble. *PLOS ONE* 13(6):e0198807. <https://doi.org/10.1371/journal.pone.0198807>
- Sanz Bas D (2020) Hayek and the cryptocurrency revolution. *Iber J Hist Econ Thought* 7(1):15–28. <https://doi.org/10.5209/ijhe.69403>
- Sanz-Bas D, del Rosal C, Nández Alonso SL, Echarte Fernández MÁ (2021) Cryptocurrencies and fraudulent transactions: Risks, practices, and legislation for their prevention in Europe and Spain. *Laws* 10(3):57. <https://doi.org/10.3390/laws10030057>
- Saranya PB (2022) Estimating the volatility of cryptocurrencies by employing garch models. *Asian J Res Bank Financ* 12(4):48–54. <https://doi.org/10.5958/2249-7323.2022.00022.0>
- Sheeran P, Spain A (2017) The South Sea bubble: From the Mississippi to the High Seas. In *The International Political Economy of Investment Bubbles* (pp. 91–107). Routledge. <https://doi.org/10.4324/9781351146364-5>
- Shu M, Zhu W (2020) Real-time prediction of Bitcoin bubble crashes. *Phys A: Stat Mech Its Appl* 548:124477. <https://doi.org/10.1016/j.physa.2020.124477>
- Shu M, Song R, Zhu W (2021) The 2021 bitcoin bubbles and crashes-detection and classification. *Stats* 4(4):950–970
- Shanaev S, Sharma S, Ghimire B, Shuraeva A (2020) Taming the blockchain beast? Regulatory implications for the cryptocurrency Market. *Res Int Bus Financ* 51:101080. <https://doi.org/10.1016/j.ribaf.2019.101080>
- Shi S, Wang BZ (2018) Bubble formation and networks in housing markets. *SSRN Electronic J*. <https://doi.org/10.2139/ssrn.3141002>
- Siegel JJ (2003) What is an asset price bubble? An operational definition. *Eur Financ Manag* 9(1):11–24. <https://doi.org/10.1111/1468-036x.00206>
- Sornette D, Woodard R (2009) Financial bubbles, real estate bubbles, derivative bubbles, and the financial and economic crisis. *SSRN Electronic J*. <https://doi.org/10.2139/ssrn.1596024>
- Sornette D, Woodard R, Yan W, Zhou W-X (2013) Clarifications to questions and criticisms on the Johansen–Ledoit–Sornette financial bubble model. *Phys A: Stat Mech Its Appl* 392(19):4417–4428. <https://doi.org/10.1016/j.physa.2013.05.011>
- Sornette D, Cauwels P, Smilyanov G (2018) Can we use volatility to diagnose financial bubbles? lessons from 40 historical bubbles. *Quant Financ Econ* 2(1):486–590. <https://doi.org/10.3934/qfe.2018.1.486>
- Szostak R (2019) The Great Depression revisited. In *Technological Innovation and the Great Depression* (pp. 3–25). Routledge. <https://doi.org/10.4324/9780429308352-1>
- Silvia JE (2021) The story of the original boom and bust in western finance: The mississippi bubble. In *Financial Markets and Economic Performance* (pp. 49–94). Springer International Publishing. https://doi.org/10.1007/978-3-030-76295-7_2
- Taskinsoy J (2019) Bitcoin: The longest running mania – tulips of the 21st century? *SSRN Electronic J*. <https://doi.org/10.2139/ssrn.3505953>
- Thompson EA (2006) The tulipmania: Fact or artifact? *Public Choice* 130(1–2):99–114. <https://doi.org/10.1007/s11127-006-9074-4>
- Urquhart A (2016) The inefficiency of bitcoin. *SSRN Electronic J*. <https://doi.org/10.2139/ssrn.2828745>
- Van Alstyne M (2014) Why Bitcoin has value. *Commun ACM* 57(5):30–32
- Vasudeva S (2023) Cryptocurrency as an investment or speculation: A bibliometric review study. *Bus Anal J* 44(1):34–50. <https://doi.org/10.1108/baj-07-2022-0008>
- Velde FR (2009) Was John Law's System a bubble? The Mississippi Bubble revisited. In *The Origins and Development of Financial Markets and Institutions* (pp. 99–120). Cambridge University Press. <https://doi.org/10.1017/cbo9780511757419.005>
- Vidal-Tomás D (2022) The new crypto niche: NFTs, play-to-earn, and metaverse tokens. *Financ Res Lett* 47:102742. <https://doi.org/10.1016/j.frl.2022.102742>
- Wang S, Chen L, Xiong X (2019) Asset bubbles, banking stability and economic growth. *Econ Model* 78:108–117. <https://doi.org/10.1016/j.econmod.2018.08.014>
- Waters GA (2019) Bubbles and rationality in bitcoin. *Econ Notes* 48(2). <https://doi.org/10.1111/ecn.12133>
- Wei D (2017) Price bubbles in bitcoin: Evidence, causes and implications. *J Shanghai Univ Financ Econ* 19(02):50–62
- Weston JL, Carswell J (1961) The South Sea bubble. *J Financ* 16(3):444. <https://doi.org/10.2307/2977342>
- Westphal R, Sornette D (2020) Market impact and performance of arbitrageurs of financial bubbles in an agent-based model. *J Econ Behav Organ* 171:1–23. <https://doi.org/10.1016/j.jebo.2020.01.004>
- Włosik K, Łęt B, Sobański K, Świder W (2022) Cross-sectional data on stablecoin characteristics. *F1000Res* 11:1188. <https://doi.org/10.12688/f1000research.126298.1>
- Wöckl I (2019) Bubble detection in financial markets - A survey of theoretical bubble models and empirical bubble detection tests. *SSRN Electronic J*. <https://doi.org/10.2139/ssrn.3460430>
- Xia H, Gao Y, Zhang JZ (2023) Understanding the adoption context of China's digital currency electronic payment. *Financ Innov* 9(1). <https://doi.org/10.1186/s40854-023-00467-5>
- Xiong J, Liu Q, Zhao L (2020) A new method to verify Bitcoin bubbles: Based on the production cost. *North Am J Econ Financ* 51:101095
- Xu Y (2023). Behavioral finance: An introduction of herd effect - Take the dotcom bubble in 2000s as an example. In *Proceedings of the 8th International Conference on Financial Innovation and Economic Development (ICFIED 2023)* (pp. 216–224). Atlantis Press International BV. https://doi.org/10.2991/978-94-6463-142-5_25
- Zhang X, Lu F, Tao R, Wang S (2021) The time-varying causal relationship between the Bitcoin market and internet attention. *Financ Innov* 7(1). <https://doi.org/10.1186/s40854-021-00275-9>
- Zheng C (2022) An innovative MS-VAR model with integrated financial knowledge for measuring the impact of stock market bubbles on financial security. *J Innov Knowl* 7(3):100207. <https://doi.org/10.1016/j.jik.2022.100207>

Acknowledgements

This article is part of the activities carried out through the research Project “Finance for all (F4A), funded by the “*Institución Gran Duque de Alba*” and “*Diputación provincial de Ávila*”, under the grant 3364/2022. The authors wish to thank their institution for its strong support of this research. The authors would like to thank the reviewers and the editor for the suggestions for improvement and proposed changes, which have improved the quality of this article.

Author contributions

Conceptualization, SLNA; methodology, SLNA; software, SLNA; validation, JJV, and MAEF; formal analysis, SLNA, and JJV; investigation, SLNA, DSB, JJV and MAEF; resources, Javier Jorge Vázquez; data curation, SLNA, and MAEF; writing—original draft preparation, JJV, and MAEF; writing—review and editing, DSB; visualization, SLNA and JJV; supervision, MAEF and DSB. All authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was not required as the study did not involve human participants.

Informed consent

Informed consent was not required as the study did not involve human participants.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1057/s41599-024-03220-0>.

Correspondence and requests for materials should be addressed to Sergio Luis Nández Alonso.

Reprints and permission information is available at <http://www.nature.com/reprints>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2024