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# Chaos Theory and Financial Markets: A Systematic Review of Crisis and Bubbles

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**ABSTRACT** Financial markets have been characterized by various financial crises and unpredictable fluctuations and price movements. While traditional finance theories, which assume that financial markets are composed of rational participants, fail to explain the market dynamics that cause crises, chaos theory provides a powerful framework to make sense of the unpredictable, deterministic nature of markets. Chaos theory claims that market fluctuations are not random but have a specific mathematical pattern.This study presents a systematic literature review addressing the relationship between chaos theory and financial crises and speculative bubbles. By analyzing articles from the Web of Science database, its relationship with crisis and bubble dynamics, and the main methodological approaches. This study explores the effectiveness of chaos theory in understanding financial instability in the context of financial crises and bubbles by examining the research questions identified for the application of chaos theory in finance through Preferred Reporting Items for Systematic Reviews and Meta-Analyses methodology and keyword analysis.

**KEYWORDS**
Chaos
Chaos theory
Financial markets
Financial crisis
Bubbles

## INTRODUCTION

Until today, financial markets have been characterised by unpredictable crises, financial instability, long-term bubbles and sharp crashes. In particular, crises such as the 1997 Asian financial crisis, the 2008 global financial crisis and the Dot-Com bubble have revealed that traditional financial theories are insufficient to explain these instabilities in the face of the fragility of the markets. The Efficient Market Hypothesis (EMH) and other neoclassical approaches assume that financial asset prices are shaped by rational actors and that market movements reach equilibrium based on information (Serletis and Rosenberg 2009). However, financial crises, high volatility, sudden price crashes, and long-term market anomalies show that markets actually have nonlinear and unpredictable dynamics. Here, more than traditional financial theories, chaos theory provides a powerful framework for understanding the deterministic yet unpredictable nature of financial systems (Ge and Lin 2022). Through concepts such as sensitive initial conditions dependence, bifurcations and strange attractors, chaos theory suggests that small changes can lead to large and unexpected consequences in the long run (Samanidou *et al.* 2007). Financial systems are affected by many internal and external variables. This structure of financial systems also forms the basis of chaotic, hard-to-predict market movements. Chaos theory differentiates itself from traditional linear models by revealing that these price fluctuations are not random, but follow certain patterns and exhibit a fractal structure (Altan *et al.* 2019; Frezza 2018).

Chaos theory provides a strong basis for explaining what happens in financial systems. However, the debate on whether financial markets exhibit a chaotic structure is still the subject of different academic studies. Contrary to the studies in the literature that prove chaotic behaviour in financial time series (Ghosh *et al.* 2022; Bianchi and Frezza 2017; Hajirahimi *et al.* 2022; Skjeltorp 2000; Gilmore 2001). Gilmore (2001) and BenSaïda (2013) argue that stochastic processes drive financial markets. These theoretical and methodological differences suggest that there are different claims used to describe the collapse in financial markets. Nevertheless, many studies on chaos and financial markets show that market movements mathematically follow certain patterns despite being unpredictable (Yuan *et al.* 2022). In this respect, chaos theory provides a strong analytical basis for explaining the unpredictable price fluctuations, bubbles and crises that characterise the evolution of financial markets. Their deterministic nature and extreme sensitivity to small changes in initial conditions can cause seemingly insignificant fluctuations in financial asset prices to turn into large-scale market movements in the long run (Wang *et al.* 2018). Sensitive dependence on the initial condition, used in the analysis of chaotic systems, shows that small movements in the markets can lead to large collapses. As a result, long-term financial forecasts quickly lose their reliability due to the accumulated error terms

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over time (Samanidou *et al.* 2007).

In recent years, there has been intense debate on the nature of financial time series. The critical question is whether these series are closer to deterministic chaotic systems or stochastic processes. The answers to this question vary greatly due to the differences in mathematical modeling approaches used. BenSaïda (2013) showed that tests performed on six different stock market indices and six exchange rate series did not confirm the chaos hypothesis. There is no consensus in the literature on the stochastic nature of financial time series. While McKenzie (2001) argues that financial time series have a stochastic structure, similarly, Tsakonas *et al.* (2022) provide evidence for the existence of chaotic dynamics based on the financial data they consider. In a different study, Altan *et al.* (2019) argue that the presence of small correlation sizes in time series suggests that the system has a certain degree of deterministic structure. All these different views deepen the ongoing debate on whether the fundamental nature of financial systems is stochastic or chaotic. However, the conceptual framework provided by chaos theory is of great importance, especially in the context of financial crises. Different financial collapses, such as the 2008 global financial crisis, have developed unexpectedly. Traditional financial risk management models have failed to predict these fluctuations and crises (Shynkevich 2016; Ouandlous *et al.* 2018; Silva *et al.* 2016; Ge and Lin 2022). Chaos theory and fractal analysis methods, on the other hand, suggest that markets exhibit chaotic behaviour within a certain order in the long run. It is claimed that this feature of financial markets can provide a more appropriate modelling framework for predicting crises (Cavalli *et al.* 2018; Frezza 2018).

Financial crises occur due to a combination of factors such as instantaneous shocks in the markets, low liquidity and high leverage (Cheriyan and Kleywegt 2016). This feature of financial crises also indicates their chaotic aspect. When considered from this aspect, the 2008 Global Financial Crisis also clearly demonstrated the destructive chaotic features of financial systems (Shynkevich 2016). While the bifurcation theory is used as an important tool in understanding such crises (Omane-Adjepong and Alagidede 2020), chaos theory also has the potential to predict crises in financial systems. From this perspective, early warning signals of financial crises are linked to chaotic features such as high volatility and systemic risk signals seen in the markets (Liu and Jiang 2020).

In this regard, the aim of this study is to provide a systematic literature review analyzing the applicability of chaos theory to financial markets, the chaotic characteristics of financial crises and the nature of speculative bubbles. The following sections of the paper will elaborate on the applicability of chaos theory to financial markets, its relationship with crisis and bubble dynamics, empirical identification methods and future research directions based on existing studies. In this sense, the next section provides a summary of the relevant literature and outlines the current state of the field. Next, the methodology section details the systematic review process used in this study. This section also presents the results of the analysis based on the keywords of the study. The results section discusses in detail the articles identified as relevant through the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) stream in the context of the research questions.

## METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), published in 2009, was introduced to ensure that researchers conducting meta-analyses and systematic literature reviews follow a common path and adhere to certain terminologies (Page *et al.* 2021). The PRISMA guideline is one of the most commonly used standards in the conduct and reporting of systematic reviews. PRISMA enhances reliability in interdisciplinary research by providing a structured framework that increases transparency, reproducibility, and methodological quality. Compared to guidelines specific to certain fields like Cochrane and CEE, PRISMA has a broader scope and is applicable to both quantitative and qualitative research. Additionally, thanks to the flow diagram that visualizes the study selection process, it helps researchers express the selection process more clearly and systematically (Belle and Zhao 2022). From the perspective of academic publications, PRISMA is one of the most preferred systematic review guidelines by high-impact journals. While the Cochrane method is primarily used in the medical field, guidelines like ROSES and ENTREQ are specific to certain disciplines and are not as widely accepted by the academic community as PRISMA (Ferdinansyah and Purwandari 2021).

The regular updates of PRISMA are also a significant advantage. With the 2020 update, new recommendations for database searches were introduced, the PRISMA checklist was made more comprehensive, and additional explanations for meta-analyses were added (Paschou *et al.* 2020). For all these reasons, PRISMA is considered an important methodology that strengthens the scientific contribution of systematic reviews and enhances reliability in research. This guideline facilitates researchers to handle academic studies in literature review studies systematically and within a certain logical framework. In this study, the PRISMA 2020 recommendations were followed and the relevant publications were selected using the detailed steps summarized below, and then examined in the context of the research questions (Page *et al.* 2021).

### Eligibility Criteria

The academic articles included in the study were selected according tog to certain criteria. These criteria are: only peer-reviewed journal articles on financial crises, bubbles, and chaos theory published in the last 10 years that address at least one of the research questions and are published in English. Articles that are not published in English, book chapters, conference proceedings, reports, letters to the editor, reviews, and conceptual articles, as well as articles that do not address any of the research questions intended to be answered within the scope of the study, are not included in the study.

### Information Sources

This study used the Web of Science (WOS) database, a globally recognised and respected resource that adheres to rigorous scientific quality criteria. The search was conducted on 20 December 2024.

### Search Strategy

The research strategy was designed for 2 main purposes. First of all, the keywords "chasos, chaos theory, chaotic, chaos applicaiton" were combined using Boolean operators according to WOS search features in order to outline the use of chaos theory in finance: ((chaos OR chaos theory OR chaotic OR chaos applications OR chaotic pattern OR chaotic behaviour) AND (finance OR financial OR financial theory)). These keywords were searched in the abstracts and keywords sections of the articles. As a result of this research, 1174 articles related to the applications of chaos in finance were reached. The results were transferred to plain text and keyword occurrence analysis was performed in VOSviewer. Figure 1. It presents the network map of the keywords created using VOSviewer software.

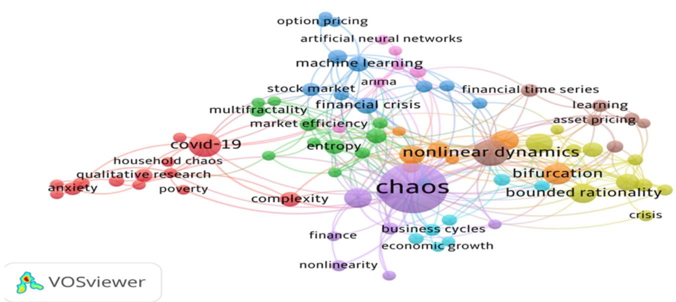


**Figure 1** Network visualization of author keywords co-occurrence

The network map shows the keyword links. The network analysis in Figure 1 shows the relationship of chaos theory and its applications with finance in the form of concentration and clustering around different topics. According to the analysis, the group indicated in red represents the themes of chaos related to COVID-19 and poverty. Another concentration of chaos in finance is asset pricing and financial time series, and this cluster is shown in brown in the network analysis. The blue coloured cluster represents the use of chaos in the stock market and financial crises, which is the main research subject of this study.

Based on this, chaos and the specified keywords were combined using Boolean operators according to WoS search features: ((chaos OR chaos theory OR chaotic OR chaos applications OR chaotic pattern OR chaotic behaviour) AND (financial market OR stock market OR financial risk management OR financial risk OR financial risk OR financial crisis* )). This keyword analysis also contributed to the formulation of the research questions presented in the next section.

### Data

The articles obtained from the WoS database using the identified keywords were compiled into a list in MS Excel format. These articles were subjected to a two-stage evaluation process. In the first stage, the abstracts of the studies were meticulously analysed and it was determined that the studies in this field focused on financial crises and bubbles, and research questions reflecting the content in this context were determined. In this process, the keyword density map shown in Figure 1 was utilised. In the second stage, 59 articles listed in MS Excel format within the scope of the research questions were scanned for titles and abstracts, and 30 articles focusing on chaos and financial crises and bubbles were obtained for final analysis. Then, similar or combinable questions were revisited and the final research questions identified below were formulated.

***Research questions (RQs):***

*RQ1.* How does chaos theory explain financial crises and bubbles and what is the empirical evidence supporting its role in financial markets?

*RQ2.* How do agent-based systems and heterogeneous agents models contribute to the understanding of chaotic dynamics in financial markets during crises?

*RQ3.* What are the main methodological approaches for modelling chaotic behaviour in financial markets, especially during financial crises and bubble formations? And which methodologies have been most effective in capturing these shocks?

After analysing the articles, it was seen that some articles addressed more than one RQ. Therefore, the articles were categorized with the Cross Classification technique.

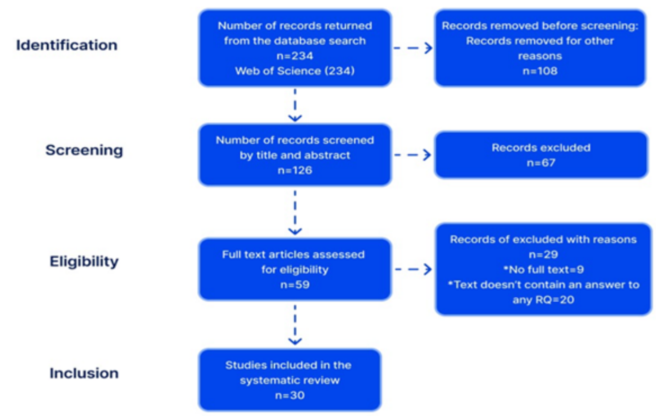


**Figure 2** PRISMA flow diagram

## RESULTS

Chaos theory, originally developed in physics and mathematics, has been widely used in financial markets to understand nonlinear, complex and dynamic processes that traditional equilibrium-oriented economic models have difficulty explaining. In this research, the first two research questions are designed to reveal the role of chaos theory in explaining financial crises and bubbles, while the last research question addresses chaos theory methodologically in modelling financial crises and bubbles.

***RQ1. How does chaos theory explain financial crises and bubbles and what is the empirical evidence supporting its role in financial markets?***

Financial markets exhibit deterministic chaos, characterised by sensitive dependence on initial conditions, non-linear interactions and feedback loops, fractal structures and self-similarity, as well as bifurcations leading to abrupt market regime changes. Financial crises and speculative bubbles occur when small perturbations grow through non-linear feedback mechanisms, leading to unpredictable but structurally deterministic outcomes. Chaos theory suggests that market fluctuations are not completely random, but instead follow hidden deterministic patterns that can be analysed using advanced mathematical techniques (Gu 2020; Lahmiri and Bekiros 2017).

Different studies have shown that chaos theory provides an important framework for explaining instabilities in financial markets (Lee *et al.* 2016). In this regard, one of the main mechanisms that are effective in the formation of financial bubbles is non-linear interactions supported by positive feedback loops (Shynkevich 2016; Todea 2016). Increasing asset prices attract more investors to the market, leading to an acceleration of price increases and causing the system to reach an unsustainable level (Vamvakaris *et al.* 2018). Gu (2020) developed a two-dimensional financial market model that shows how interactions between market actors with different investment strategies lead to chaotic fluctuations in stock prices. Similarly, Lahmiri and Bekiros (2017) find that the volatility clustering observed in global markets is not only caused by stochastic fluctuations, but also chaotic dynamics play a decisive role in this process.

Another important aspect of chaos in financial markets is that small-scale shocks can move markets from one equilibrium state to another and cause sudden collapses (Yin and Wang 2019). This situation is considered within the scope of bifurcation and catastrophe theory and plays a critical role in understanding the fragile structure of markets (Cheriyan and Kleywegt 2016). Cheriyan and Kleywegt (2016) developed a dynamic system model that explains how bubble formation and market cycles are shaped through bifurcation processes. On the other hand, Dercole and Radi (2020) analyse the effects of short selling restrictions on market dynamics and show that regulatory interventions can unexpectedly trigger speculative bubble formation.

Empirical studies to investigate the existence of deterministic chaos in financial markets utilise various chaos-based methods. One of these approaches is the calculation of Lyapunov exponents to distinguish chaotic structure from random processes by measuring the deviation rate of a system's close trajectories (Tsionas and Michaelides 2017; Wang *et al.* 2014; Yin and Wang 2019; Tsakonas *et al.* 2022).Tsionas and Michaelides (2017) revealed the deterministic nature of financial returns in their study in which Bayesian inference method was applied to determine Lyapunov exponentials in stock markets. In addition, Lahmiri and Bekiros (2017) argue that Shannon entropy and Kolmogorov complexity increase during financial crisis periods, suggesting the existence of a hidden deterministic order underlying financial markets.

Complexity measures used in financial time series provide important evidence on whether markets exhibit chaotic dynamics. Entropy-based approaches stand out as an effective method to analyse the level of randomness and structural features in financial data (Sanjuan 2021; Bariviera *et al.* 2015; Lahmiri and Bekiros 2017; Wang *et al.* 2018; Nie 2021; Ge and Lin 2022) . Lahmiri and Bekiros (2017) use permutation entropy and statistical complexity measures to detect chaotic patterns in international stock and commodity markets and find that market movements show certain patterns. On the other hand,Bariviera *et al.* (2015) applied complexity-entropy causality analysis to identify manipulations in LIBOR rates, showing that financial markets have a structure that appears random on the surface but is actually affected by certain chaotic processes. Financial crises can spread rapidly through the linkages between global markets, resulting in complex network structures that exhibit chaotic dynamics. Using correlation clustering methods, Nie (2017) reveals that post-crisis market configurations are reshaped in a chaotic manner due to non-linear dynamics.

While chaos theory provides important support in predicting financial crises and fluctuations, it also has some limitations. One of the main limitations is that financial systems are extremely sensitive to initial conditions and the reliability of long-term forecasts is severely limited due to the butterfly effect (Tsionas and Michaelides 2017). Moreover, Lahmiri and Bekiros (2017) and Tsionas and Michaelides (2017) argue that high-dimensional stochastic processes can mimic chaotic dynamics, so it is difficult to conclusively establish the existence of deterministic chaos in financial markets. Therefore, the issue of separating chaotic processes from stochastic noise is among the ongoing academic debates. Moreover, advanced chaos-based approaches such as Lyapunov exponents, fractal analysis and hybrid deep learning models pose technical challenges as they require high computational power (Altan *et al.* 2019; **?**). Moreover, financial market structures transform over time due to changes in regulatory frameworks, macroeconomic policies and global developments, making it difficult to apply certain chaos-based models in a consistent and sustainable manner.

***RQ2. How do agent-based systems and heterogeneous agents models contribute to the understanding of chaotic dynamics in financial markets during crises?***

Financial markets are prone to sudden price fluctuations and systemic instability during financial crises, especially due to nonlinear feedback mechanisms, heterogeneous expectations and complex network interactions (Silver *et al.* 2022). Traditional finance theories such as the EMH and the Rational Expectations Hypothesis (RES) argue for the efficiency of markets by assuming that market participants behave rationally and that market information is interpreted the same by all participants (Shynkevich 2016; Bianchi and Frezza 2017). However, empirical studies testing these theories show that these assumptions fail to fully explain market dynamics in reality (Wang *et al.* 2018; Silver *et al.* 2022).At this point, intermediary-based models and heterogeneous intermediary models offer an alternative approach that analyses the micro-level interactions of different investor profiles and their effects on macroeconomic instability (Majewski *et al.* 2019; Bowden 2012). These models provide an important analytical framework for understanding the emergence and evolution of financial crises and how they spread across markets.

Beyond modelling investor behaviour, agent-based and heterogeneous agent models offer important insights into how systemic risk and market contagion are shaped during financial crises. During periods of financial distress, systemic risk tends to spread due to interdependencies among financial institutions in the banking system. By analysing the cluster structure of financial networks, Nie (2017) shows that crises reduce the size of market correlations and that this spillover process is not random but deterministic based on certain chaotic dynamics. Ma *et al.* (2019), using an agent-based model of interbank networks, show how fire sales and increased leverage levels trigger financial instability and create self-feedback loops. In addition, Bella and Mattana (2020) show that uncontrolled speculative growth leads to unpredictable bifurcations, further complicating crisis management. These studies show that financial crises are not only caused by exogenous factors, but also shaped by deterministic chaotic feedback mechanisms within financial networks.

Different studies in the literature provide empirical results supporting the deterministic nature of financial markets.Wang *et al.* (2014) analyse financial contagion during the 2008 financial crisis by means of Maximum Lyapunov Exponents and find that it follows chaotic trajectories characterised by spikes in Maximum Lyapunov Exponents values. Lu (2020), on the other hand, developed a chaotic control framework and showed that market crashes are not only caused by exogenous shocks but also by bifurcation processes. This finding supports that financial instability is largely caused by the internal structure of market dynamics. Similarly, Ghosh *et al.* (2022), using the Log-Periodic Power Law method to analyse financial bubbles, confirmed that speculative price increases exhibit self-similar chaotic patterns. These results question the conventional wisdom that financial crises are completely unpredictable and suggest that financial markets, despite their chaotic nature, allow for a certain probabilistic forecasting structure.

The findings of the studies in the literature also have important implications for financial regulation and policy makers. The fact that financial markets have a chaotic structure and crises may have a feedback mechanism may cause traditional financial models to be insufficient (Silva *et al.* 2016). Kozłowska *et al.* (2016) propose an early warning system based on bifurcation monitoring to predict systemic crashes in financial markets. In addition, Ma *et al.* (2019) argue that limiting leverage levels together with restrictions on speculative investment strategies can prevent chaotic fluctuations in financial markets.

Furthermore, Bariviera *et al.* (2015) reveal chaotic fluctuations in financial markets with real-time regulatory supervision based on complexity-entropy measures. The findings of these studies suggest that regulators should use flexible and dynamic policies that are compatible with the chaotic nature of financial markets instead of traditional policies against crises and chaotic fluctuations in financial markets

***RQ3. What are the main methodological approaches for modelling chaotic behaviour in financial markets, especially during financial crises and bubble formations? And which methodologies have been most effective in capturing these shocks?***

Chaotic fluctuations in financial markets, especially during crisis periods and bubbles, are analysed with different methodological approaches in the literature. One of these methodological approaches is Lyapunov exponents and structural break models. Wang *et al.* (2014)Wang et al. (2014), in their study on the S&P 500 index, identified the critical regime change points during the 2005-2012 financial crisis using the Maximum Lyapunov Exponents technique. The findings reveal that the financial contagion process proceeds in four main stages: stationary period, local contagion, global contagion and recovery. These stages provide an important framework to better understand the nonlinear nature of crises and their impact on markets. This method has become a powerful tool for crisis analyses by effectively identifying regime shifts in financial systems.

Another methodological approach that reveals chaotic waves and dynamics in financial markets is chaotic system control techniques. According to this approach, Lu (2020) argues that chaotic fluctuations in financial markets can be regulated and markets can achieve a more balanced structure. This study, which recommends the use of the feedback control method to reduce the impact of crises, emphasises that it can be an effective tool for financial chaotic fluctuations to gain a periodic and more predictable structure.

Stochastic volatility models stand out as an important analytical tool in detecting financial shocks.Kim *et al.* (2021) developed the Hybrid Stochastic and Local Volatility model by adding new features to traditional stochastic volatility models to better capture unpredictable fluctuations in over-the-counter markets, especially during crisis periods. Similarly, Ouandlous *et al.* (2018) analysed the VIX index, which is widely used as an indicator of uncertainty in financial markets, and found that this index exhibits long memory and power law dynamics. Their research shows that the VIX index permanently reflects extreme volatility events, especially during major crashes such as the 2008 global financial crisis, and thus demonstrates the necessity of nonlinear modelling approaches in financial market analysis. In addition, Lee *et al.* (2016) investigate the pricing of European fragile options when the underlying asset has a dynamic structure within the framework of the Heston model. The paper derives a closed-form analytical solution for option pricing under the classical Heston model that incorporates stochastic volatility. Moreover, the effect of stochastic volatility on option prices compared to the Black-Scholes model is examined and the relationship between the rate of decline of option prices with credit risk and the level of monetization is analyzed. These findings support the critical role of stochastic modelling in understanding the chaotic nature of financial markets.

Advances in machine learning and metaheuristics have significantly improved financial modelling processes (Ozkurt 2024). Altan *et al.* (2019) developed chaotic metaheuristic bio-inspired forecasting methods by combining deep learning techniques such as Long Short Term Memory neural networks with Empirical Wavelet Transform and Cuckoo Search algorithms. The findings reveal that these hybrid models significantly improve the forecasting accuracy of cryptocurrency prices, especially those exhibiting high fractality and chaoticity. Furthermore, Frezza (2018) developed a fractal-based approach to model real price movements by assuming that prices obey a Random Exponential Multi-Fractional Process. Through comparisons on three different stock indices, he provides empirical evidence that this stochastic process is highly consistent with real data series. Integrating machine learning into financial chaos analysis enables more accurate forecasts and contributes to a better understanding of the dynamic structure of markets.

Change point detection and financial contagion analysis are among the frequently used methods to identify sudden changes in dependency structures in financial markets. Wang *et al.* (2014) applied Core Change Point Detection and Convergent Cross Mapping methods to detect sudden changes in dependency relationships in markets. Their research shows that financial crises lead to unexpected breaks in market dynamics and such changes are not adequately captured by traditional linear models. The capacity of these models to identify sudden changes in market structures makes them highly valuable for monitoring financial instability in real time and developing early warning systems for crises.

Bifurcation theory and early warning indicators offer important insights into chaotic dynamics in financial markets. Kozłowska *et al.* (2016) show that financial systems can be subject to catastrophic bifurcation failures, where small-scale disturbances can cause large and unpredictable changes over time. Their research emphasises the importance of early warning signals, such as tremor phenomena and slowdown effects, which can help anticipate financial collapses. Bella and Mattana (2020) elaborate on the role of Shilnikov chaotic attractors in the formation of financial bubbles, showing that such bubbles develop in line with chaotic processes and ultimately lead to financial crises. They also proposed a control mechanism based on the Ott-Grebogi-Yorke method to stabilise market volatility and reduce uncertainty. These studies support the necessity of continuous monitoring of bifurcation points in financial markets in order to anticipate impending crises. Third level section text. These headings may be numbered, but only when the numbers must be cited in the text.

Systemic risk analysis has utilised network-based approaches to better understand the propagation mechanisms of financial shocks. Ma *et al.* (2019) examine systemic risk in banking networks and find that financial shocks propagate through interbank credit structures and portfolio diversification mechanisms. Their study emphasises that the heterogeneity of network structures is a critical factor in mitigating the risk of widespread financial contagion. Similarly, Nie (2017) used correlation dimension techniques to analyse financial market clustering, and the findings suggest that financial crises often lead to a reduction in market complexity with a contraction in correlation dimension, which makes systemic risks more pronounced. In addition to understanding how financial contagion occurs, the integration of network-based modelling approaches provides an important framework for financial institutions to manage systemic risk more effectively.

The Table 1 summarizes the fundamental studies that include different methodological approaches used to model the chaotic dynamics in financial markets. The methods used in the studies and the findings obtained are presented comparatively, emphasizing which analytical techniques are more effective in understanding crises and bubble formations.

**Table 1** Summary of fundamental studies and their methodological approaches

| Article | Methodology | Findings |
|---|---|---|
| Gu (2020) | Two-dimensional financial market model | Stock prices exhibit chaotic fluctuations due to non-linear effects. |
| Lahmiri and Bekiros (2017) | Volatility clustering analysis | Chaos plays a significant role in market volatility patterns. |
| Cheriyan and Kleywegt (2016) | Dynamic system model | Bubble formation and market cycles explained by non-linear interactions. |
| Dercole and Radi (2020) | Market dynamics under regulatory restrictions | Regulatory interventions can trigger unexpected speculative bubbles. |
| Tsionas and Michaelides (2017) | Bayesian inference for Lyapunov exponents | Deterministic nature of financial returns detected. |
| Wang *et al.* (2014) | Structural changes analysis using Lyapunov Exponents | Financial contagion proceeds in multiple structured stages. |
| Yin and Wang (2019) | Artificial Neural Networks | Oil price prediction improved using chaos-informed Artificial Neural Networks models. |
| Nie (2017) | Financial network cluster analysis | Financial crises reshape market configurations non-randomly. |
| Lu (2020) | Chaotic control framework | Bifurcation processes contribute to market crashes. |
| Ma *et al.* (2019) | Agent-based interbank network model | Systemic risk propagates through banking network structures. |
| Altan *et al.* (2019) | Chaotic metaheuristic bio-inspired forecasting | Hybrid forecasting models enhance accuracy in chaotic markets. |
| Frezza (2018) | Fractal-based modelling approach | Stock prices follow a structured but chaotic fractal pattern. |
| Kozłowska *et al.* (2016) | Bifurcation monitoring for systemic crashes | Small disturbances can trigger large and unpredictable changes. |

## RESULTS AND DISCUSSION

This study analyses the link between chaos theory and financial markets, crises and speculative bubbles through a systematic literature review. The results show that the complex and unpredictable fluctuations observed in financial markets do not occur randomly, but follow certain dynamic patterns. Chaos theory contributes to a better understanding of financial instability by providing a powerful analytical framework for understanding sudden price movements, crises and bubble formation that traditional finance approaches have difficulty in explaining.

The research discussed in this study reveals that financial time series may exhibit chaotic dynamics and these features can be analysed by methods such as Lyapunov exponents, fractal analysis and log-periodic power law. In addition, there are ongoing debates regarding the existence and validity of chaotic movements in financial markets. This group of studies suggests that financial data is fundamentally driven by stochastic processes (Lahmiri and Bekiros 2017; Lee *et al.* 2016; McKenzie 2001; BenSaïda 2013). Studies Omane-Adjepong and Alagidede (2020); Gu (2020); Cheriyan and Kleywegt (2016); Belle and Zhao (2022), that claim the opposite support their claims with evidence supporting the existence of deterministic but unpredictable price movements through chaotic attractors and bifurcation mechanisms.

Financial crises and speculative bubbles are inherently affected by chaotic processes. The fact that small changes in initial conditions can lead to large market fluctuations over time is one of the basic concepts put forward by chaos theory. In particular, large-scale financial collapses such as the 2008 Global Financial Crisis reveal the decisive role of non-linear dynamics in markets. Studies reveal that market volatility, systemic risk factors and financial network connections should be analysed in detail in order to predict crises.

However, the application of chaos theory in financial markets involves various difficulties. One of the most important of these challenges is the limited reliability of long-term forecasts due to the high sensitivity of financial systems to initial conditions. Moreover, distinguishing chaotic processes from stochastic noise becomes very difficult due to the high computational costs and modelling complexities of existing methods. However, advanced computational techniques, deep learning algorithms and agent-based modelling approaches are expected to make significant contributions to better understand and analyse the chaotic nature of financial markets.

Chaos theory provides an alternative framework for analysing market fluctuations by offering new insights into the dynamics of financial crises and speculative bubbles. However, more empirical studies are needed in the future to better understand its validity in financial markets. In particular, research supported by large-scale financial data, machine learning techniques and advanced time series analyses can more clearly reveal the role of chaos theory in market mechanisms.


### Availability of data and material

Not applicable.

### Conflicts of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

### Ethical standard

The author has no relevant financial or non-financial interests to disclose.

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