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Review Article

Understanding Financial Market Unpredictability: The Rise of Agent-based Models and Stylized Facts

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Abstract - *The unpredictable behavior of financial markets is a result of dynamic interactions, differing individuals, and random events. The efficient market Hypothesis and rational expectations are both conventional theories used to explain the nature of the market. Still, they have not taken into consideration the complexity and crises of the real world. The limitations of traditional theories are reviewed, a discussion of the evolution and diversity of Agent-Based Models (ABMs) as a new paradigm follows, and the value of using stylized facts is discussed to determine the credibility and usefulness of ABMs. The paper highlights the bottom-up simulation characteristics of ABMs, which are better suited to modelling and capturing economic events in the real market in comparison to traditional systems. The results show that the realism and explanatory capacity of financial market models are much improved by the merging of behavioral and computational intelligence methodologies. In addition, the significance of stylized facts as a key benchmark to verify model performance and compliance with empirical facts is emphasized. This research offers to the prior study by intertwining multiple research streams and identifying key research gaps, and presents an organized framework for further research in hybrid finance modeling frameworks.*

Keywords - *Agent-based model, Behavioural biases, Efficient market hypothesis, Financial market, Stylised facts.*

1. Introduction

Financial market is a place in which money is traded, such as in the form of commodities, shares, debts, currencies, and derivatives. Because it facilitates the flow of funds and financial instruments, it is essential to the financial system, as it helps people retain or make investments, organisations finance programs, and companies expand. What is the primary characteristic of financial markets? What is the most important feature of financial markets? The prices of bonds, stocks and other investments can go up and down; it is impossible to predict their future value exactly. Some investors consider this to be a risk, while others consider this to be an opportunity to benefit. However, they all take part in the market.

The financial market is a highly volatile market, given the ongoing dynamics of global, psychological, political and economic factors. The price of assets (e.g., stocks, bonds and currencies) can fluctuate quickly in reaction to news, market sentiment, policy shifts, and surprise disasters. Due to this ambiguity, it is challenging to make accurate predictions about future market behavior. Others see this change as an opportunity for money, others see this change as a risk. While numerous models and strategies have been developed to describe market dynamics, predicting the financial market is difficult due to the ongoing complexity and the impact of human behaviors and external factors.

Investors aren't always logical. Fears, greed, terror, and enthusiasm can affect market decision-making and lead to sudden, erratic price movements. News of election results, wars, epidemics, natural disasters, and economic events triggers reactions in the market right away. They are often unexpected and have a major impact on asset values. These are the expectations of investors and the direction of the market, and they are all susceptible to the whims and wiles of a changeable set of indices such as low wages, rising prices, interest costs and GDP. Investors' general confidence or mood might change rapidly.

Regardless of the truth, even speculation or talk has the power to drastically alter markets. Global financial markets are extremely intertwined. Shocks in one country can have a global impact, e.g., an economic crisis, political unrest. Algorithms and auto trading systems respond instantaneously to market data. This can cause volatility and swift fluctuations, which can make it more difficult to predict the outcome accurately. Financial markets are always volatile, complex and nonlinear. However, conventional financial simulations tend to assume equilibrium, rationality and perfect knowledge, which are not accurate descriptions of the uncertain realities of actual markets. EMH is a basic study, which says that price contain all available information. However, true to its name, this point of view has been called into question by actual research, especially in times of financial crisis or financial


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distress. So, Agent-Based Models (ABMs) are gaining popularity as a suitable alternative in the absence of better market conditions.

In the vast amount of data markets assess in real time, it can be difficult to separate out useful information from the noise, even with the most sophisticated models.

Although the financial markets may be volatile in the short term, they have a tendency to follow predictable patterns over the long term. These trends are not absolute, but they form the basis of fairly general recommendations that can aid analysts and investors in making decisions. In the long run, large stock markets (like the S&P 500) have shown a trend of rising prices over time, despite the fluctuation of short-term movements.

In the long run, the prices of large stock markets (like the S&P 500) are generally upward trending over time, despite the significant fluctuations in the short term.

1.1. Conceptual Evolution in the Financial Market

Analysis: EMH-Stylized Facts/Behavioural Finance-AMH & ABM

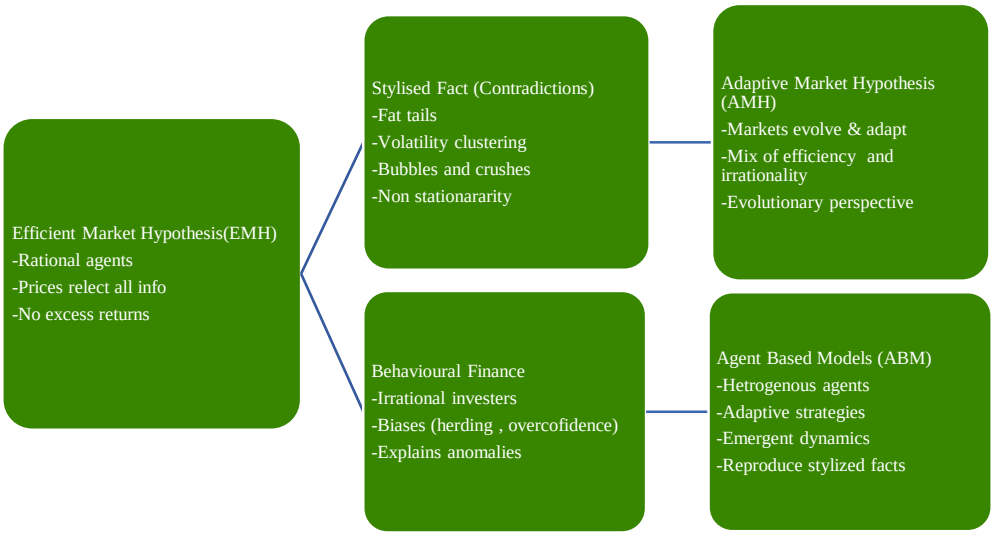


Fig. 1 Conceptual evolution

Fama used his model's interpretation to offer useful suggestions for an investment plan. Samuelson explained and advanced a political skill by interpreting his model. A fundamentalist agent mainly bases their trading decisions on basic data. In contrast, a chartist agent thinks that an asset's potential return can be predicted based on the historical pattern of achieved returns.

2. Efficient Market Hypothesis

One of the especially important theories in the economic market is Efficient-Market-Hypothesis. This hypothesis, which was originally formulated in the 1960s by Eugene F. Fama, states that the stock market deal with data extremely effectively. According to EMH, asset prices accurately and instantly represent all accessible data, making it challenging for investors to generate returns that exceed the industry average regularly. Stock price fluctuations follow a random pattern in an efficient market because price changes occur only when new, unexpected information becomes accessible.

EMH is divided into three classifications, based on the degree of information reflected in asset values:

Weak-Form Efficiency: All past market data, including trading volumes and costs, is reflected in pricing. Because of this, techniques like economic assessment are unable to consistently provide surplus profits.

Semi-strong-Form Efficiency: Prices reflect all publicly available information, including updates, financial reports, and economic metrics. The market cannot be continuously outperformed by either Analytical or fundamental evaluations.

Strong-Form Efficiency: Prices take into account all data, private as well as public, especially personal knowledge. Under this kind of arrangement, even insider trading is unable to offer exceptional profits.

The EMH has greatly impacted financial theory and investment practices. It affirms the theory that passive investment techniques, like index funds, have grown in popularity because aggressive trading strategies might not always beat the market. EMH provides a framework for understanding how information is factored into asset values and how financial markets efficiently allocate resources.

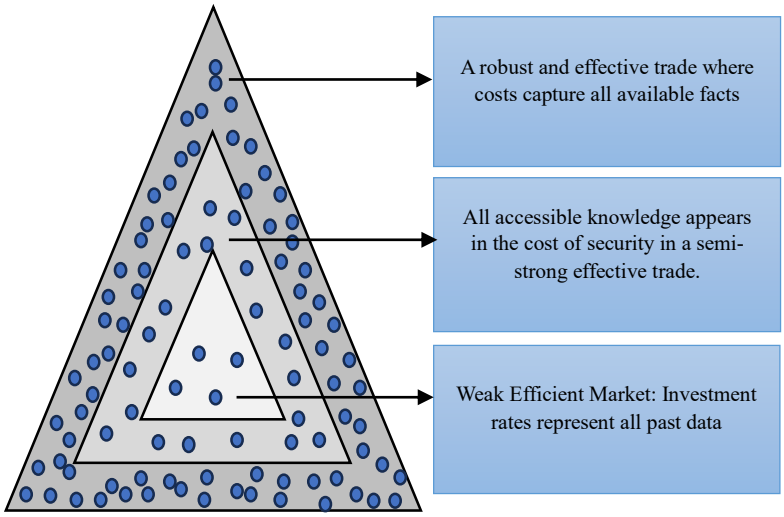


Fig. 2 Categories of EMH

Table 1. Literature survey of EMH theories

Author (Year)	Title	Explanation
Abhay Kumar et al. (2020) [23]	The testing of the efficient market hypothesis: A study of Indian Pharmaceutical Industry	This study looked at weak form, semi-strong form, and strong form efficiency with a focus on the Indian pharmaceutical industry. The authors discovered that financial market did not accurately reflect all accessible data using corporate and stock price data. The study emphasized the existence of market flaws and information delays, particularly in sector-specific markets where investor reactions can be slower.
Alves et al. (2020) [24]	Collective Dynamics of Stock Market Efficiency	Investigated the dynamic character of market efficiency in international stock markets and discovered that, rather than staying constant, efficiency varies with time.
Nartea, Valera & Valera (2021) [25]	Mean Reversion in Asia-Pacific Stock Prices	Some Asia-Pacific markets showed signs of mean reversion, indicating departures from weak-form market efficiency.
Yasmin Akter Bipasha (2022) [26]	Market Efficiency, Anomalies and Behavioral Finance: A Review of Theories and Empirical Evidence	Bipasha examined how behavioral finance theories, market oddities, and EMH are related. The study highlighted that investor psychology, cognitive biases, and emotional decision-making often cause departures from logical market behavior. Examples included herding behavior, momentum effects, loss aversion, and overconfidence. The paper contended that behavioral finance, in conjunction with traditional EMH, offers a more practical explanation of financial market dynamics.
Diamond & Perkins (2022) [27]	Using Intermarket Data to Evaluate the Efficient Market Hypothesis with Machine Learning	The semi-strong variant of EMH was tested in this work using machine learning techniques. To forecast stock returns, the researchers used data from several financial marketplaces. Their models outperformed chance in predicted performance, indicating that public knowledge is not always quickly incorporated into markets. The results showed the increasing significance of artificial intelligence in financial forecasting and contested the semi-strong version of EMH.
Xu (2023) [28]	Efficient Market Hypothesis in Contemporary Applications	examined EMH in contemporary financial markets and concluded that while EMH is still significant, some market inefficiencies are revealed by machine learning and sophisticated forecasting methods.
Kulikova & Kulikov (2022) [29]	Estimation of Market Efficiency Process within Time-Varying Models	demonstrated how market efficiency changes over time and is impacted by crises and economic events, supporting the Adaptive Market Hypothesis.

Nazlioglu et al. (2024) [30]	Efficient Market Hypothesis in Emerging Stock Markets	It was shown that structural shifts and information asymmetry cause efficiency levels to differ greatly among emerging markets.
Jiang et al. (2025) [31]	The Efficient Tail Hypothesis: An Extreme Value Perspective on Market Efficiency	The"Efficient Tail Hypothesis," which emphasizes exceptional market events over typical market circumstances, was presented by the authors. They examined how markets respond to financial crises and times of great volatility using extreme value theory. According to the study, during extreme occurrences, efficiency tends to decrease as a result of investors' emotional reactions and the poor diffusion of information. This study highlighted the shortcomings of the conventional EMH during market stress.
Fang Wang & Marko Gacesa (2023) [32]	Semi- strong Efficient Market of Bitcoin and Twitter	This study investigated whether the efficiency of the Bitcoin market is impacted by information from social media, specifically Twitter. The authors discovered that social media mood affects cryptocurrency returns by examining millions of tweets in conjunction with Bitcoin pricing. The findings partially supported semi-strong efficiency by indicating that some price swings can be explained by publicly available information. But the presence of predictable sentiment impacts also suggested inefficiencies in the market.
Butet & Kesuma (2025) [33]	Efficient Market Hypothesis: A Systematic Literature Review	concluded that there is conflicting evidence for the EMH and that behavioral biases, anomalies, and emergent market characteristics often challenge classic EMH assumptions.
Anil Kumar & Neha (2025) [34]	Testing the Weak Form Efficient Market Hypothesis: An Interpretive Study of Market Efficiency	Weak-Form-Market effectiveness in several financial markets was reexamined in this interpretive study. After reviewing the actual data, the authors concluded that market efficiency fluctuates. Rather, efficiency varies according to investor engagement, technology improvements, market maturity, and regulatory restrictions. AMH, which contends that market effectiveness changes with time, was bolstered by their research.
Amitabh Satapathy (2025) [35]	Test of Random Walk Hypothesis in Indian Stock Market and Verify any Relationship Between Market Efficiency and Liquidity	Satapathy investigated the connection between market liquidity and the random-walk hypothesis in the Indian stock trade. According to the study, more liquid stocks typically show higher efficiency since information is assimilated more rapidly. Less liquid stocks, on the other hand, displayed more indications of inefficiency and predictability. The results showed how crucial trade activity is to assessing market efficiency.
Jain et al. (2021) [36]	The Evolution of Efficient Market Hypothesis: A Systematic Literature Review with Bibliometric and Thematic Analysis	Behavioral finance, adaptive markets, FinTech, cryptocurrency markets, and crisis-driven market inefficiencies are among the significant research topics that have been identified.
Wang et al. (2025) [37]	Is All the Information in the Price?LLM Embeddings versus the EMH in Stock Clustering	In this study, Large Language Model (LLM) embeddings from textual data were compared to conventional price-based information. The authors investigated if advanced AI techniques could uncover data that wasn't previously reflected in stock prices. The findings supported the EMH by demonstrating that market prices include a substantial amount of information. However, projections were sometimes enhanced by AI-generated insights, suggesting that markets are not entirely efficient.

Julio Lobao, Luis Julio Pacheco & Nuno Cruz (2026) [49]	On the Evolution of the Stock Market Efficiency: Evidence From Emerging Markets	It looks at how market effectiveness changes as time goes on in developing economies. The study makes a connection between the AMH and the conventional Efficient Market Hypothesis (EMH). Its main contention is that investor behavior and market conditions can affect market efficiency, therefore, it shouldn't be viewed as a fixed state. This offers a solid theoretical link between EMH and AMH.
Si-Qi Mao et al. (2026) [50]	Is the Financial Market Efficient? An Advanced Time Series Analysis	In order to examine market efficiency, it presents BERT-based financial sentiment research along with sophisticated time-series analysis. The study is especially useful because it uses textual data and financial news in addition to historical pricing, expanding the scope of typical EMH testing. It shows how information efficiency can be examined using sentiment analysis, NLP, and financial-market prediction.
Yifan Liu & Shi-Dong Liang (2026) [51]	A Global Optimal Theory of Portfolio beyond R-σ Model	It offers a portfolio framework that takes return, risk premium/arbitrage-related opportunity, and volatility into account and specifically addresses departures from the EMH. The Chinese stock trade is used in the study's numerical analysis. It serves as a helpful theoretical work that illustrates how scientists are creating models that go beyond conventional EMH presumptions.
Ryuji Hashimoto et al. (2026) [52]	Financial Market as a Self-Organized Ecosystem: Simulation via Learning with Heterogeneous Preferences	The study creates a multi-agent reinforcement-learning artificial market where agents have varying learning capacities, risk aversion, information access, and preferences. Realistic financial market features like volatility clustering and fat-tailed returns are produced by the model. It establishes a clear link between market efficiency, heterogeneous agents, learning, and ATM and offers a computational interpretation of the Adaptive Market Hypothesis.

Numerous industry variations and behavioral biases that the432zx theory is unable to adequately explain have been discovered by researchers. Due to these constraints, alternative theories like Behavioral Finance, Adaptive Market Hypothesis, and Agent-Based Computational Economics were developed. These theories take into account investor psychology, learning, and interactions among heterogeneous agents in an effort to explain financial market behavior.

3. Stylized Facts of Financial Markets

A set of strong statistical regularities that hold across asset classes, markets, and historical periods has been reliably confirmed by empirical investigations of financial markets. These regularities are known as stylized facts. These empirical characteristics offer a crucial standard for assessing financial market models and cast doubt on the presumptions of traditional financial theories. The fat- tailed distribution of asset returns is one of the most well-known stylized facts.

Early research by [22] and later work by [7] demonstrate that financial returns exhibit excess kurtosis, indicating that large price movements occur more often than identified by a normal distribution. This leptokurtic pattern is seen in the stock, commodities, foreign currency, and derivatives markets, suggesting that Gaussian-based models frequently predict a low tail risk.

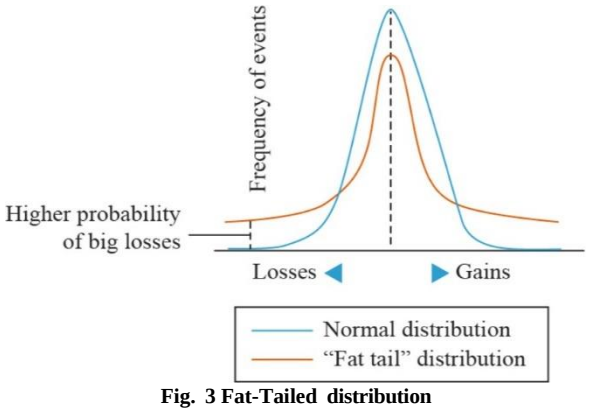


Fig. 3 Fat-Tailed distribution

Another well-documented feature is volatility clustering, where large price moves are generally followed by larger ones and small ones by weaker ones, independent of direction. This pattern indicates continuity in volatility and has been observed in several market conditions and at varying rates. While returns themselves exhibit minimal or no continuous biases, measures of volatility, such as averaged or absolute return, exhibit significant serial dependence on it.

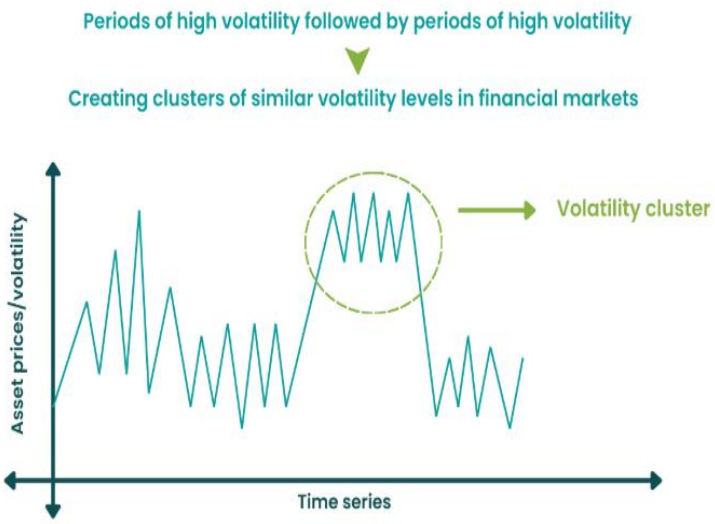


Fig. 4 Volatility clustering

A key empirical measurement of financial time series is sharing of correlates with volatility. and uncorrelated returns. The long-memory property of Volatility clustering is linked to volatility. Empirical evidence shows that volatility dissipates over long periods of time with a long-range memory and not a short one, stochastic behavior. This is a finding that contradicts the basic models of this type, which are used to model the highly nonlinear temporal structure in the dynamics of the market.

Aggregational Gaussianity, in which return distributions tend to become more Gaussian as the sampling interval grows, is another phenomenon seen in financial markets. At longer time scales, the distribution progressively approaches normality despite the very non-normal short-horizon returns, which is consistent with a generalized central limit effect.

Furthermore, research has shown a strong association between trading volume and volatility, suggesting that heterogeneous trading behavior and information flow are important factors in price formation. Lastly, asymmetries in return-volatility relationships, also known as leverage effects, show that future volatility is increased more by negative returns than by positive returns of the same size. The modeling of financial dynamics is made more difficult by these asymmetries, which are especially noticeable in equity markets.

4. Agent-based Models in Financial Market Studies

One of the most intricate systems ever developed by humans, the global financial system is arguably the greatest illustration of chaotic dynamics. This system comprises emergent rules of engagement and several interacting autonomous agents (elements). The agents typically have diverse objectives, norms of interaction, and methods of decision-making. Global system dynamics, whether toward equilibrium or disequilibrium, in the pricing of different assets are driven by the interactions between numerous agents.

In the representative agent framework, general equilibrium theory is applied by most analytical techniques used to investigate financial markets. It is assumed in this paradigm that every actor maximizes their objective function with complete information and logic. One of the main tenets of this modeling philosophy is that understanding the system as a whole may be achieved by analyzing each component. It usually falls short in accounting for stylized realities, particularly in financial markets, even if it aims to develop analytical answers for further study. This is largely because many models in this framework overlook the emergent features of agents' interactions and their diverse strategies, instead making several unrealistic assumptions, including market clearing, market convergence to equilibrium prices, perfect information, and rationality. The unthinkable outcomes of their interconnections, as well as the variety and interaction among market participants, imply that this discipline currently lacks a solid micro-level base.

The bottom-up method, known as Agent-Based Modeling (ABM), which was initially developed in the late 1940s, has provided a more compelling theoretical foundation for general equilibrium analysis than the earlier top-down methods. The behaviors of agents in an Agent-Based Model (ABM) are both autonomous and diverse; each agent is free to operate according to its own set of rules and engages with every other agent in an autonomous manner inside a specific area that offers the distinct data needed for system analysis. ABMs effectively connect the macro behavior of asset prices in real markets with the micro-level norms of investor

behavior by including these characteristics, which are seen in actual financial markets [2, 33].

When examining the dynamics of financial markets, ABM offers several advantages. First, by demonstrating that agents behave in an artificially intelligent manner, ABM circumvents the error of mathematical formulas developed using the general equilibrium theory. Second, it is simple to control both agent behavior and ambient factors when ABM is used. As a result, this transformation allows one fundamental model to generate various models. Third, because agent interaction invariably results in a distinct and chaotic system over time, observers can detect both the model's threshold and emergent systemic features and phenomena in the ABM scenario.

ABM can investigate new areas of economic study thanks to these advantages of simplicity, flexibility, and emergence, particularly in dynamic markets with asymmetric knowledge, learning, and uncertainty. However, when combined, they provide challenging technological problems in terms of practicality and computational viability. The design, calculation, and verification of ABMs-which aim to assess the effects of autonomous agents' interactions and actions on the system as a whole-have become easier due to notable advancements in computer power and the collection of real-world data during the 1990s. There are other difficulties. The majority of the time, ABM is still complex, making it challenging to identify important factors influencing the distinctive behaviors of agents. Furthermore, there may not be enough analytical answers due to the method's intrinsic complexity. ABM also introduces novel and unproven methods, somewhat flimsy underlying presumptions, and maybe missing crucial parameters. Consequently, a thorough ABM design is essential for addressing any potential flaws. The studies that apply ABMs to financial markets in different contexts are compiled in this article, which also takes into consideration market architecture, agents' action rules, and their dynamic evolution as determined by the corresponding models.

4.1. Different Agent-Based Model (ABM) Theories in Financial Markets

4.1.1. The Artificial Stock Market in Santa Fe

By simulating financial markets as systems of diverse, boundedly rational agents that learn and adapt over time, the Artificial Stock Market (ASM), created by W. Brian Arthur and others at the Santa Fe Institute, challenges the premises of the Efficient Market Hypothesis. The ASM enables agents to employ a variety of forecasting tactics and update them using adaptive methods like genetic algorithms, as opposed to depending on perfectly rational investors and equilibrium conditions. Realistic market phenomena like bubbles, collapses, excessive volatility, and fat-tailed return distributions result from prices emerging endogenously from supply and demand interactions. All things considered, the model shows that financial markets are dynamic, changing systems propelled by agent interactions. It also established the groundwork for contemporary adaptive market theories and agent-based computational finance [26].

4.1.2. Lux-Marchesi Model

Compared to the Efficient Market Hypothesis, this model provides a more realistic explanation of market dynamics by classifying traders into two major groups: fundamentalists and noise traders. As far as noise trading is concerned, such traders use trends, herd behavior, and market mood to oscillate between optimistic (buying) and pessimistic (selling) attitudes. On the contrary, fundamentalists believe that prices will tend towards the intrinsic value of assets and trade using information about mispricings. Depending on the respective earnings and the state of the market, agents may alternate between the two categories, and this switching process is regulated through stochastic transitions, as per statistical physics. If fluctuations in the attitudes of noisy traders are influenced by both price trends and majority behavior, the change in price stems from endogenous mechanisms involving supply and demand mismatch due to the activities of such agents. In addition, the basic intrinsic value itself changes randomly (normal distribution), ensuring the emergence of market swings due to intrinsic dynamics rather than shocks coming from outside the system [20].

4.1.3. The Minority Game Model

`Building on the analogy between the El Farol Bar problem and the stock market, Challet D. and Zhang Y.-C. (1997) constructed the so-called Minority Game (MG), which is a simple but highly effective simulation game modeling adaptive behavior in financial markets. The idea behind it lies in the belief that there are benefits in standing out among other people, which means that in the minority game, multiple agents constantly make decisions (buying or selling, for instance), while those who are in the minority win. Bounded rationality and learning in the model become evident in the sense that each agent applies a limited set of strategies determined by past performance and changes his mind if the new strategy seems more efficient than others. Although the MG model is very easy, it generates highly complicated dynamics which strongly correspond to the financial markets, like excess volatility, clustering of volatility, or fat tails of the return distribution. Moreover, the model demonstrates that, unlike to the Efficient Markets Hypothesis, market efficiency does not always happen and comes temporarily due to the agents' competition and easily vanishes when too many individuals play the same game, leading to bubbles and crashes and, hence, herding [3].

4.1.4. Cont-Bouchaud Model

Based on scientific findings, stock returns and price movements exhibit fat tails and not a Gaussian distribution since large price changes occur much more often than expected. The situation, characterized by high kurtosis,

persists even after allowing for time-varying volatility. New information or fundamentals are unable to explain such significant shifts in prices, showing that herd behavior contributes to such shifts. Herd behavior arises when investors mimic what other people do in the financial markets, thus bringing in crowd effects that bring about disequilibrium and sudden increases in volatility. There may be scant literature regarding herd behavior from a theoretical perspective; however, there is sufficient evidence regarding the existence of herd behavior through experiments. Herd behavior is believed to influence return distributions and price movements [8].

4.2. The Heavy-Tailed Nature of Asset Return Distributions

There is a high degree of kurtosis in financial assets such as stocks, indexes, and futures returns. Such returns have high kurtosis, that is, excess kurtosis, which is higher than zero, and also have extreme price changes occurring more often than can be anticipated through a normal distribution. The high kurtosis cannot solely be attributed to different distributions such as heteroskedastic (ARCH/GARCH), stable distribution, and subordinated process, particularly because of their finite variances and persistent non-normalities. This implies that significant price fluctuations are not exclusively caused by shifting volatility or outside variables. Rather, more recent methods emphasize herding behavior among agents (such as fundamentalists and noise traders) and market contacts as important factors. These models provide a more straightforward and understandable explanation of actual market behavior by amplifying demand fluctuations through imitation and group dynamics, which can result in abrupt, significant price shifts and naturally produce fat-tailed return distributions.

4.3. Herd Behavior in Financial Markets

Investors frequently mimic the activities of others, according to empirical data from fund managers, mutual funds, and analysts. This shows that mimetic (herding) behavior is a major contributing reason to excessive volatility in financial markets. Although herding may appear illogical, other theories contend that it might be in line with the best course of action when faced with ambiguity or when social factors are at play.

In financial markets, when numerous decisions are made at once, it is impractical for traditional models, such as information cascade models, to assume that agents make judgments sequentially by watching others. Other methods, including those based on the Ising model, capture imitation but are unable to replicate realistic return distributions.

In order to get around these restrictions, more recent models suggest that agents communicate via random communication networks, creating groups that mimic one another while still permitting behavioral variation. This paradigm helps explain how complex phenomena like volatility and heavy-tailed return distributions can be produced via collective imitation and more accurately represent actual market conditions.

4.4. Aggregation of Random Individual Demands

According to this model, aggregate excess demand-the total of all individual trading decisions-is what drives overall price fluctuations in a stock market with several agents who can buy, sell, or do nothing. Liquidity is what determines sensitivity, and it is supposed that price changes depend on this additional demand. The Central Limit Theorem postulates that if agents behave independently, then return is normally distributed, although this postulate is defeated by reality, where returns are characterized by high kurtosis and fat tails. Some theoretical models account for this effect either through heteroscedasticity or infinite variance distributions, but in fact, financial series display limited variance with fat tails. The independent-agent approach's primary drawback is its disregard for agent interactions and communication. In actuality, traders organize into clusters or groups (such as funds or herding groups) where they operate together and exchange information, resulting in correlated behavior. This model provides a clearer explanation for large markets' wings and fat tails in return distribution as emergent phenomena from collective behavior as opposed to separate occurrences, through modeling such interactions in terms of random communication whereby agents coordinate and aggregate into groups.

4.4.1. The Model Developed by Kim and Markowitz (1989)

According to Lee et al. (1989), the development of the Intelligent Stock Portfolio Management System was a step away from traditional mathematical models, such as the ones advanced by Markowitz in his portfolio theory and CAPM models. The qualitative judgment employed by human specialists was not captured by earlier models, which solely concentrated on quantitative elements like risk and return. In order to get around this, the authors created a rule-based expert system that integrated quantitative information with qualitative elements, including industry perspective, management caliber, and market trends. It helped build transparency and trust through a decision-making model based on if-then decisions and provided explanations for the rationale behind its suggestions. It helped build transparency and trust through a decision-making model based on if-then decisions and provided explanations for the rationale behind its suggestions. Although the system did not consider any interaction between agents, the research is considered one of the pioneers of agent-based modeling, as it used a large number of decision rules and tactics [18].

4.4.2. Models of LeBaron

The authors Lee et al. (1989) created a mixed model by combining a rule-based expert system to create a link between statistical data and non-statistical factors such as managerial quality and market trend. The article is a forerunner of the

agent-based modeling approach because the work shows that making investment decisions consists of using many tactics, not only mathematical optimizations. Agent-based Computational Finance (ACF) is an approach that emerged in the '90s and views financial markets as complex systems with several interacting and adapting agents. In other words, this approach explains real-world phenomena such as speculative bubbles, crashes, and volatility, thus contradicting the Efficient Market Hypothesis (EMH) based on perfectly rational actors. An example is the Santa Fe Artificial Stock Market, where speculative bubbles and market inefficiencies emerge from the existence of adaptive agents. Another example of the application of agent-based modeling in finance is provided by Blake LeBaron, who shows how agents can produce realistic phenomena of fat-tailed distributions and volatility clusters. A model created by Thomas Lux and Michele Marchesi helps better understand how speculative bubbles and market instability occur as a result of interactions among different groups of traders, such as fundamentalists and chartists [17].

4.4.3. Farmer et al. (2005) Proposed the Farmer's Zero-Intelligence Model

The Zero Intelligence Theory was introduced for the first time by Farmer et al. (2005). This theory underscores the significance of market structure over that of the intelligent traders.

In this theory, the agents do not make use of any strategy or logic while placing their orders. Instead, they follow the practice of ordering randomly. The fundamental point here is that the trading process in itself is capable of indicating the nature of the market. This demonstrates that rational or knowledgeable traders are not always necessary for complex market activity. The model contests the Efficient Market Hypothesis by claiming that institutional regulations and market design have a significant impact on market efficiency in addition to rational decision-making [31].

4.4.4. ABM Perspective on the Adaptive Market Hypothesis (Lo, 2004)

The Adaptive Market Hypothesis was put forth by Andrew Lo (2004) as a substitute for the Efficient Market Hypothesis. In contrast to EMH, that holds markets are always rational and effective, AMH contends that, like biological evolution, market efficiency varies over time as investors adjust to novel circumstances. AMH highlights the diversity of investors, their limited capacity for reason, and their constant learning and strategy adjustment. A changing market environment results from the survival of successful strategies and the disappearance of ineffective ones.

Additionally, it explains actual market behaviors (stylized facts) like:

- Efficiency changes with time
- Clustering of volatility
- Crashes and bubbles as inevitable results of herd mentality and adaptation.

Table 2. Mapping AMH principles to ABM features

Adaptive Market Hypothesis (Lo, 2004) [48]	Agent-Based Model (ABM) Feature	Explanation
Evolutionary dynamics-Markets change over time, much like biological ecosystems	Survival-of-the-fittest dynamics in a population of diverse agents	Similar to natural selection, agents in ABMs who employ profitable methods continue to exist and proliferate, while those that do not are eliminated.
Context-dependent efficiency -Markets can fluctuate between stages of efficiency and inefficiency.	Simulation-based time-varying market regimes	Similar to AMH's concept of growing efficiency, ABMs naturally create regime transitions (such as calm vs. crisis times) based on collective behaviour.
Heterogeneity of participants-Different methods coexist.	Various agent rules (noise traders, chartists, fundamentalists, etc.)	Because AMH places a strong focus on diversity in market players, ABMs specifically mimic diverse trading tactics.
Adaptation and learning-Traders make adjustments based on feedback and experience.	Adaptive heuristics, strategy switching, and reinforcement learning	Similar to how AMH proposes traders adjust over time, agents in ABMs learn or switch between tactics based on payoffs.
Bubbles and crashes are natural phenomena.	Emergent market instabilities	ABMs demonstrate how systemic dynamics arise without supposing irrationality by reproducing bubbles, crashes, and volatility clustering from agent interaction.
The role of institutional environment regulation, innovation, and structure shapes markets.	Microstructure and rule-based design in ABMs	ABMs demonstrate how systemic dynamics arise without supposing irrationality by reproducing bubbles, crashes, and volatility clustering from agent interaction.

4.5. From EMH to AMH through ABM

Adaptive and evolutionary approaches to market dynamics have replaced static equilibrium viewpoints in the development of financial market theory. The first theoretical approach that provided a coherent framework to understand rationality and informational efficiency of prices was presented through the EMH, which was describe by Fama and Samuelson. But this did not account for the stylized facts such as the existence of Fat-Tails in returns distribution, the presence of asset price bubbles, and volatility clustering. Instead, an In Lo's (2004) Adaptive, an adaptive approach is provided. Adaptive Market Hypothesis (AMH), which recognizes the fact that market efficiency will adapt and change with adaptation. Competition of traders in different environments. This is in accordance with the notion behind Agent-Based Models (ABMs), which were developed to view the market as an ecosystem of a set of elements, including consumers, producers, and the goods and services themselves. When heterogeneous and bounded rational agents interact, this results in behaviours emerging. The tools for creating a personal website. must know that adaptation and evolution of participating in AMH can help increase the efficiency of markets.

5. Behavioural Biases and Investor Decisions

Heterogeneous agents can be included using ABMs various behavioral biases, such as loss aversion, herd behavior and overconfidence, in contrast to traditional assumptions of homogeneous and perfectly rational models individuals. These models help study the micro-hows. Macro-level market behavior is an outcome of micro-level behavioral principles. By modelling interactions between agents, dynamics are created. Previous research has revealed that such behavioural distortion has a considerable impact on investment and/or market results. Freedom to choose, particularly during times of uncertainty. Consequently, a more realistic representation of a financial market where price creation, volatility, and trading patterns emerge endogenously with agent interactions is made possible by incorporating. Take behavioral finance concepts and incorporate them into an ABM. This method not only overcomes the knowledge gap between theory and practice, but also puts theory into practice. and real market practices, as well as a more profound understanding of the part psychological elements plsay in. In addition to bridging the gap between theory and actual market behavior, this method offers a greater knowledge of the role of psychology in contributing to market inefficiencies.

Table 3. Summary of literature on behavioral finance

Author(s) & Year	Focus of Study	Key Findings
Valcanover, Sonza & Silva (2020) [38]	Behavioral Finance Experiments: A Recent Systematic Literature Review	Analyzed experimental research and emphasized the significance of investment biases, heuristics, and prospect theory in explaining departures from rational conduct.
Rasool & Ullah (2020) [53]	Financial literacy and investor baises in the stock market	Investigated how behavioral biases like overconfidence and investing choices are influenced by financial literacy. The study demonstrated that the degree to which psychological biases impact financial decisions can be influenced by investor knowledge.
Raheja & Dhiman (2020) [54]	The influence of emotional intelligence on investment decisions and behavioral baises	Examined the connection between cognitive distortions and psychological ability. The study emphasized how crucial psychological and emotional aspects are when making investment decisions.
Okorie & Lin (2021) [55]	Adaptive market hypothesis: The Story of the stock markets and COVID-19 pandemic	Showed that during times of crisis, market efficiency can alter. The results demonstrate how shifting investor behavior can affect market performance and support the AMH.
Khursheed et al. (2021) [56]	Adaptive market hypothesis: An Empirical analysis of time-varying market efficiency of cryptocurrencies	Efficiency fluctuates with time, according to research on cryptocurrency marketplaces. The study shows that periods of efficiency and inefficiency can result from shifting market conditions and investor behavior.
Yasmin Akter Bipasha (2022) [26]	Market efficiency, anomalies and behavioral finance: A review of theories and empirical evidence	Shown how the Efficient Market Hypothesis (EMH) is challenged by irregularities in the market such as momentum, overreaction, and herd behavior.
Sundavadara & Sanghvi (2024) [39]	Behavioral finance: A systematic literature review	Overconfidence, anchoring, representativeness, herding, and loss aversion were the most commonly researched investor biases in behavioral finance studies conducted between 2011 and 2023.

Shah & Butt (2024) [57]	Heuristic baises and investment decision-making of stock market investors: A review paper	Examines the main heuristic biases that affect stock market investment decisions, such as representativeness, availability, gambler's fallacy, anchoring and overconfidence.
Bagchi, Prasad & Shrivastava (2024) [58]	Behavioural biases in financial investments: A comprehensive literature review	Overconfidence, conservatism, regret aversion, anchoring, mental accounting, herding, loss aversion and confirmation bias all have a substantial impact on investment decisions, according to research on behavioral biases.
Kanapickienė et al. (2024) [59]	A comprehensive review of behavioral baises in financial decision-making from classical finance to behavioral finance perspectives	Explains how behavioral finance has replaced classical finance, which is based on rational investors and EMH. It highlights cognitive constraints and psychological aspects as reasons for anomalies in the market.
Hachicha, Argoubi & Guesmi (2024) [60]	The knowledge domain and emerging trends in behavioral finance: A scientometic analysis	Identifies key research issues, such as investor sentiment, risk, prospect theory, asset bubbles, and decision biases, by analyzing 2,056 behavioral finance papers.
Gorzon, Bormann & Von Nitzsch (2024) [61]	Measuring Costly behavioral bias factors in portfolio management: A review	Explores how behavioral factors can lead to investment expenses and underperformance and reviews behavioral biases that affect portfolio performance.
Sharma & Negi (2025) [40]	Effect of behavioural baises on investors decision making: A systematic literature Review	It was found that investor judgments are significantly influenced by emotions and cognitive baises rather than only logical analysis. This has an effect on portfolio performance and market efficiency.
Katenova, Frolova & Schmunkamp (2025) [41]	Behavioral finance in the sphere of investment: systematic review of literature Between 2020 and 2025	Emphasized the increasing significance of fintech platforms, social impact, digital investing, and psychological biases in contemporary investment behavior.
Idris (2025) [42]	A Systematic literature review of investor financial behavior: Determinants, Biases, and decision-making patterns	Found that the main factors influencing investment behavior were herding, loss aversion, overconfidence, financial knowledge, and demographics.
MR Alam, A Ahmad, J Akhter, T Aziz (2025) [43]	Mapping the Field of Behavioral Finance: Systematic Review and Bibliometric Analysis	Discovered that investor sentiment, financial literacy, prospect theory, herding behavior, and behavioral biases were the most prevalent study themes after analyzing 175 significant publications.
Herdiana et al. (2025) [44]	Global Research Frontiers and Thematic Evolution in Behavioural Finance	Demonstrated how research has moved away from classic behavioral biases and toward sentiment analysis, fintech, AI-driven investing, and digital finance.
Namboothiri, Senthilkumar & Pandey (2026) [62]	Investor Herding Behavior: A Systematic Literature Review and Future Research Agenda with TCCM Framework	It identifies significant research themes, hypotheses, and methodological approaches after reviewing 179 studies. According to the study, investors might follow other market players' moves instead of depending only on their own knowledge, which could lead to market inefficiencies, bubbles, and excessive volatility.
Liu He (2026) [63]	Incorporating Cognitive Baises into Reinforcement Learning for Financial Decision-Making	In this work, reinforcement-learning models incorporate behavioral-finance notions like loss aversion and overconfidence. It is significant because it shows how conventional rational-agent presumptions can be expanded using behaviorally informed AI agents and links psychological biases with contemporary computational financial decision-making.
Shumiao Ouyang & Pengfei Sui (2026) [64]	Dissecting AI Trading: Behavioral Finance and Market Bubbles	The study looks into how AI/LLM trading agents behave in financial market simulations. It identifies patterns like the disposition effect and recency-weighted views that are

		similar to human behavioral biases. Crucially, the study is extremely pertinent to agent-based financial-market modeling since these individual actions can combine to create market-level events like bubbles.

6. Research Gap

The absence of a thorough and empirically supported paradigm that may explain financial-market volatility through interactions between diverse behavioral agents and adaptive learning mechanisms is the main research gap. Conventional financial models frequently use the assumption that investors are homogeneous and rational, which restricts their capacity to describe intricate market occurrences.

While Agent-Based Models (ABMs) offer an appropriate framework for representing diverse agents, previous research often reproduces just specific stylized facts or concentrates on a small number of behavioral traits. Moreover, there is still a lack of research on the combination of machine learning and adaptive learning methods. Therefore, a unified ABM framework is needed to capture behavioral interactions and simultaneously reproduce multiple financial stylized facts.

7. Conclusion

The application of conventional finance theories, such as Efficient Market Hypothesis (EMH), nonetheless yields limited predictive accuracy, despite the underlying complexity, variability, and volatility of financial markets. Based on the notion that stock prices represent all relevant data, the Efficient Market Hypothesis offers a basic conceptual framework; however, it fails to explain market anomalies, biases, or periods of over-volatility. Apart from market efficiency, heterogeneous expectations, bounded rationality, and adaptive decisions made by investors are all factors that are considered in the analysis of various stylized features of financial markets, which include the existence of fat-tailed return distribution and volatility clustering, which allowed for the evaluation and confirmation of many ABM systems using empirical results. The results of this paper reveal that ABM models perform much better in terms of replicating these crucial stylized features than other models.

This indicates their capability in modeling complex financial phenomena resulting from collective behaviors rather than logical assumptions. There are also some disadvantages of ABM models besides their strengths. The sensitivity to parameters, high computational costs, and model calibration are still serious challenges to overcome. Thus, the main focus of future research is on the next step should be to improve the robustness and scalability of such system better models.

The optimization uses machine learning techniques in their role as agents, the agents' actions, parameters, and recognizing patterns. One possible approach is to treat certain of the data within the massive data sets as one possible direction. High-frequency data will also help to increase the models' accuracy and sensitivity over time. Lastly, yet another interesting prospect would be to make hybrid models of ABMs to be used that leverage the best of both worlds: classical and financial models. This will create an environment where: likely to help in raising performance and better and more efficient production. Explanatory power, more accurate predictions.

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