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NOISY TRADER BEHAVIOR IN ADAPTIVE MARKETS: DECISION-MAKING BIASES AND MODELING APPROACHES

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Abstract: This paper examines the debate between the Efficient Market Hypothesis (EMH) and the Adaptive Market Hypothesis (AMH), focusing on trader behavior, market dynamics, and decision-making biases. The EMH asserts that markets reflect all available information, making consistent outperformance impossible. However, persistent market anomalies such as mean reversion, price momentum, and excess volatility challenge this view, prompting the development of the AMH.

The AMH frames market efficiency as dynamic, evolving with environmental changes and participant adaptation. Drawing from evolutionary psychology, it explains how diverse market participants - from institutional investors to noise traders - shape outcomes through competition and adaptation. Traders' decisions under uncertainty are influenced by biases like overconfidence, herding, and loss aversion.

Noise traders, acting on perceived but irrelevant information, contribute to inefficiencies while enabling liquidity and trading opportunities for informed investors. Their persistence highlights "limits to arbitrage," where rational traders cannot fully correct price distortions due to market frictions. Portfolio biases such as home bias, familiarity bias, and risk aversion further affect investment decisions. Rational inattention theory explains how cognitive limitations force selective information processing, leading to suboptimal behavior.

To model these processes, we propose advanced machine learning techniques like Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) with Long Short-Term Memory (LSTM) and Gated Recurrent Units (GRU). These models capture temporal patterns and evolving biases.

In conclusion, this research bridges EMH and AMH by linking trader behavior, cognitive biases, and market adaptability, offering a novel framework for understanding market dynamics and pricing inefficiencies.

Keywords: *adaptive markets, noisy traders, decision-making biases, neural networks, bias-driven behavior*

Efficient market hypothesis (EMH) versus Adaptive market hypothesis (AMH)

Critics of the Efficient Market Hypothesis (EMH) find strong support in the presence of serial dependencies in stock market data and the success of straightforward investment strategies. If asset prices truly followed a martingale process, such patterns and profitable

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investment rules would not exist. However, their persistence in the data, even long after being publicly recognized, indicates a flaw in the EMH framework. What value does even the weakest form of the EMH hold if strategies like mean reversion and price momentum consistently outperform the market? While it's possible that an unidentified risk explains these returns, such a significant risk should be apparent given the returns observed, yet no such risk has been clearly identified so far. *(Burton, E., & Shah, S., 2013).*

The Efficient Markets Hypothesis (EMH) is one of the most influential concepts in intellectual history, sparking ongoing debates between its supporters and advocates of behavioral economics and finance. At its core, the EMH implies that active portfolio management is unnecessary. Given the success of this journal over three decades, it seems appropriate to revisit this foundational theory. In an informationally efficient market, price changes should be unpredictable if they accurately reflect all relevant information and expectations of market participants. Roberts and Fama formalized this concept with Fama's famous phrase, "prices fully reflect all available information," by defining different levels of information accessible to investors. Today, the EMH framework is often summarized by the "three P's of Total Investment Management": prices, probabilities, and preferences. These principles are rooted in the fundamental economic concept of supply and demand. (Fama, E.F., 1970). Psychologists and experimental economists have identified several behavioral biases that deviate from the Efficient Markets Hypothesis (EMH), highlighting common irrationalities in human decision-making under uncertainty. These biases, such as overconfidence, overreaction, loss aversion, herding, mental accounting, probability miscalibration, hyperbolic discounting, and regret, can negatively impact an individual's economic well-being. Critics of the EMH argue that investors frequently, if not consistently, behave irrationally in predictable and financially harmful ways. Grossman and Stiglitz take this criticism further by asserting that perfectly efficient markets cannot exist. If markets were fully efficient, there would be no incentive to gather information, as no profits could be made, ultimately reducing trading activity and causing market failure. (Grossman, S. J., & Stiglitz, J. E., 1980). The extent of market inefficiency influences how much effort investors are willing to put into gathering and trading on information. A stable market equilibrium can only exist if enough profit opportunities, or inefficiencies, exist to justify the costs of trading and information acquisition. The profits earned by these informed investors can be seen as "economic rents" gained by those who actively pursue such opportunities. But who provides these rents? Black offered an intriguing explanation: "noise traders" - individuals who trade based on what they mistakenly believe to be valuable information, but which is actually just random noise. (Black, F. (1986).

The sociological context surrounding the Efficient Markets Hypothesis (EMH) debate suggests that a shift from the traditional deductive framework of neoclassical economics may be needed. One promising direction, proposed by Farmer and Lo, involves applying evolutionary principles to financial markets. This approach draws on the emerging field of evolutionary psychology, influenced by Wilson's work on applying competition, reproduction, and natural selection to social behavior. It provides compelling explanations for various human behaviors, including altruism, fairness, kin selection, and moral reasoning.

By integrating these principles, the EMH can be reconciled with behavioral finance, forming a new framework: the Adaptive Markets Hypothesis (AMH). The AMH reinterprets market efficiency through an evolutionary lens, where prices reflect available information based on environmental conditions and the diversity and behavior of market participants, referred to as "species" in an economic ecosystem. Each species represents a distinct group of investors with similar behavior, such as pension funds, retail investors, market makers, or hedge fund managers.

When multiple species, or a dominant species, compete for limited resources within a market, that market becomes highly efficient. Thus, market efficiency is not static but context-dependent and dynamic, evolving like ecological systems, where populations rise and fall in response to environmental changes, competition, and adaptation. (Lo, A.W. 2004).

According to AMH, markets can be efficient at times, but this efficiency is not permanent. It depends on the behavior and adaptability of market participants, who are constantly learning and adjusting to new information and changing conditions. Unlike the EMH, which assumes markets always reflect all available information, AMH suggests that markets evolve and can become more or less efficient depending on external conditions. Behavioral biases, like overconfidence or loss aversion, may influence prices, but these effects may diminish as participants adjust. The success of investment strategies depends on the current market context. A strategy that works well in one environment (bull market, high liquidity, low volatility) may fail in another (bear market, economic crisis). As market conditions shift, investors must continually adapt their strategies to survive, leading to an ever-changing landscape of market dynamics. This adaptability contrasts with the static assumptions of the EMH, where a single strategy can work consistently. The AMH suggests that there are periods of relative stability when market conditions allow for more efficient functioning, but also periods of instability where markets are more inefficient due to shocks, crises, or other external factors. During times of instability, market inefficiencies become more pronounced, but as participants learn and adapt, markets gradually regain efficiency. Just as species evolve through natural selection, market participants evolve through a process of financial selection. Those who can adapt to changing market environments survive and succeed, while others are driven out of the market. This evolutionary process means that market participants' behaviors, investment styles, and strategies are constantly evolving, leading to shifts in market efficiency over time. AMH bridges the gap between two previously conflicting theories: the Efficient Market Hypothesis and Behavioral Finance.

- **No single strategy works all the time**: Investors must continuously adapt their strategies to align with the current market environment.
- **Behavioral finance is important**: Investors should be aware of their own biases and the biases of others, as they can create opportunities in inefficient markets.
- **Risk management** is essential: Since markets evolve and may become inefficient, strategies need to be flexible, and investors must manage risk, especially in periods of instability.
- **Opportunities arise from inefficiencies**: While the EMH suggests it's hard to consistently outperform the market, AMH implies that adaptive investors can find opportunities during periods of inefficiency Lo, A. W., (2005).

We can summarize all above mentioned approaches in Table 1.

Table 1

The aspects of the Efficient Market and Adaptive Market Hypothesis'.

Aspect	Efficient Market Hypothesis (EMH)	Adaptive Market Hypothesis (AMH)
Core Concept	Markets are always efficient, reflecting all available information instantly.	Markets evolve and adapt due to changing environments and agent behaviors.
Market Behavior	Prices follow a random walk and cannot be predicted.	Prices change based on market participants' adaptation and learning.
Information Processing	All relevant information is immediately reflected in prices.	Market efficiency varies; information processing depends on experience, learning, and adaptation.
Assumptions About Agents	Investors are rational and maximize utility.	Investors are boundedly rational with behavioral biases that adapt over time.
Market Conditions	Constant market efficiency regardless of external changes.	Efficiency depends on environmental conditions like competition, regulation, and market shocks.
Trading Strategies	Active trading cannot consistently outperform the market.	Adaptive strategies can be profitable depending on evolving market conditions.
Market Anomalies	Anomalies like bubbles and crashes should not exist.	Anomalies are expected due to changing behaviors and learning processes.
Mathematical Framework	Based on models like the Capital Asset Pricing Model (CAPM) and Random Walk Theory.	Incorporates elements from evolutionary economics, behavioral finance, and complexity theory.
Practical Implications	Passive index investing is recommended due to efficiency.	Adaptive strategies, active management, and market-timing can be effective.
Long-Term View	Markets remain efficient in the long run.	Markets continuously evolve; efficiency is context-dependent.
Criticism	Overly idealistic, ignoring real-world complexities.	Hard to quantify and apply consistently due to adaptive nature and complex feedback loops.

Source: Developed by authors.

For us the main interesting aspect of this hypothesis is how traders (noisy and informed) perceive information, evaluate the informativeness of the information, and make biased or non-biased decisions.

Noise and Noisy Traders

Noise plays a dual role in financial markets: it enables trading but also introduces imperfections. Without noise trading, trading in individual assets would be minimal. Jaffe and Winkler propose a model where speculative markets are stabilized by traders who adjust their risk exposure, overestimate their forecasting skills, or trade for reasons unrelated to maximizing expected returns for a given level of risk. Similarly, Figlewski's model identifies two types of traders with different forecasting abilities. Since neither type fully considers the other's information, both end up trading based partly on noise.

Noise trading occurs when traders act on perceived information that is actually irrelevant. These traders engage in the market despite being objectively better off staying out, possibly because they mistakenly believe the noise they act on is valuable information — or simply because they enjoy trading. This activity fills a crucial gap in the market, sustaining liquidity and enabling price discovery, even if it leads to market inefficiencies. (Jaffe, J. F., & Winkler, R. L. 1976).

One reason traders engage in noise trading is simply that they enjoy it. Another reason is the abundance of noise in the market, making it difficult to distinguish real information from irrelevant signals. Many traders believe they are acting on valid information when, in fact, they are responding to noise.

Kahneman and Tversky provide a more advanced explanation through their behavioral decision-making model, which explores why people often make seemingly irrational choices. Their framework could help explain the motivations behind noise traders' behavior. For applications of their theory in economics and finance, see works by Russell and Thaler. Meanwhile, stock prices and returns are directly observable. Historical return volatility can be measured, and using daily return data, the current volatility of a stock's returns can be estimated with reasonable accuracy. Similarly, the correlations among returns on different stocks can be closely monitored and analyzed. Russell, T., & Thaler, R. (1985).

Noise or uncertainty has its effects in economic markets because there are costs in shifting physical and human resources within and between sectors. If skills and capital can be shifted without cost after tastes and technology become known, mismatches between what we can do and what we want to do will not occur. (Black, F.1986)

Rational Expectations Equilibrium (REE) models assume that traders act rationally, maximizing expected utility based on beliefs consistent with the model itself. While these models acknowledge the presence of "noise," it is typically considered a random error in the aggregate excess demand function rather than the result of incorrect beliefs. The precise origin of noise is not deeply explored within the REE framework, as traders are assumed not to act strategically, and learning from prices occurs within equilibrium rather than in real time. Trading activity is simplified, with agents submitting demand functions to a theoretical auctioneer.

For noise traders to persist, there must be barriers that prevent them from being eliminated by more informed traders, commonly referred to as "smart money." This concept relates to the "limits to arbitrage." One such barrier could be a limited trading horizon for smart money investors. With a restricted time frame, noise traders might push prices further from their fundamental values, causing losses for rational traders. This idea is explored in works by DeLong, Shleifer, Summers, Waldman, Dow, Gorton, and Shleifer and Vishny, who argue that such limits to arbitrage explain the continued existence of noise trading in financial markets. (Dow, J., & Gorton, G., 2006)

Noise traders mistakenly believe they possess unique information about future prices of risky assets. In response, sophisticated investors adopt strategies to profit from these misperceptions. They buy when noise traders drive prices below fundamental values and sell when prices are pushed too high. While these contrarian strategies help correct mispriced assets, they do not fully restore prices to their true values.

This partial correction gives rise to various financial market anomalies explained by noise trader risk. Examples include excessive volatility and mean reversion in stock prices, the breakdown of the expectations hypothesis in the term structure of interest rates, the Mehra-Prescott equity premium puzzle, the undervaluation of closed-end mutual funds, and other persistent market irregularities. (De Long, J. B., Shleifer, A., Summers, L. H., & Waldmann, R. J., 1990).

The question of market equilibrium in the presence of agents who do not update their expectations according to Bayes' rule has been explored by Russell and Thaler. They conclude that having some rational agents in the market does not ensure a rational expectations equilibrium if quasi-rational agents are also present. Jarrow extends this analysis by examining market equilibria with agents holding diverse expectations.

Supporting the overreaction hypothesis, empirical evidence shows that portfolios of previously underperforming stocks (“losers”) tend to outperform portfolios of past high-performing stocks (“winners”). Thirty-six months after portfolio formation, the losing stocks generate returns approximately 25% higher than the winners, despite the winners being notably riskier. This suggests that market overreaction creates profit opportunities, challenging the assumption of fully rational markets. (De Bondt, W. F. M., & Thaler, R. 1985)

Casual observation suggests the content of financial news about the stock market could be linked to investor psychology and sociology. However, it is unclear whether the financial news media induces, amplifies or simply reflects investors’ interpretations of stock market performance.

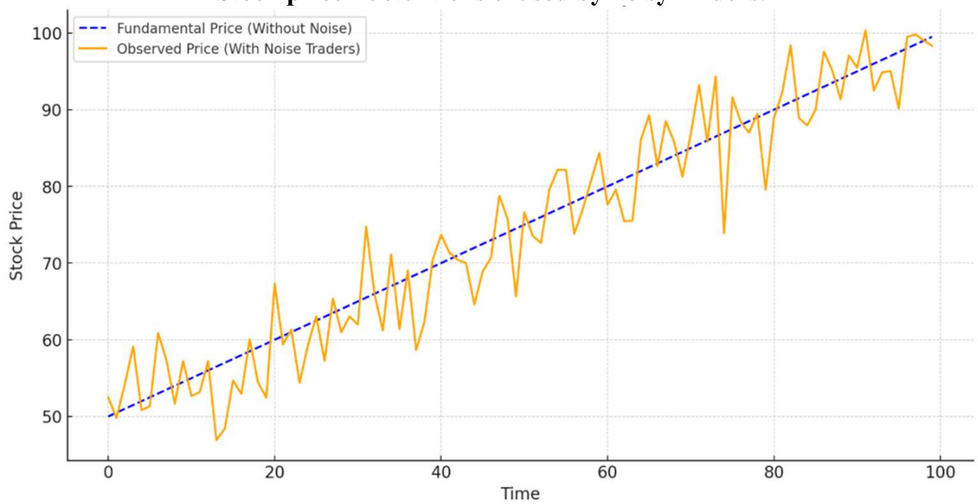
1. **Focus on Salient Information Over Fundamentals**: Noise traders often react more to salient information than to underlying fundamentals. For example, they may make investment decisions based on recent price trends, media hype, or market sentiment without considering the intrinsic value of the asset. This leads to volatility and irrational market movements, as noise traders buy or sell based on what seems most attention-grabbing at the moment.
2. **Overreaction and Mispricing**: Salient information can trigger overreactions in noise traders. For instance, during market bubbles, noise traders may overvalue stocks based on rapidly increasing prices, ignoring warnings of overvaluation. Similarly, during market downturns, they may panic and sell off assets due to overly salient negative news, even if the fundamental outlook hasn't changed.
3. **Herding Behavior**: Salient information can also fuel herding behavior, where noise traders follow the crowd rather than relying on independent analysis. For example, when media outlets repeatedly emphasize a market trend, such as a rapidly growing sector, noise traders may jump on the bandwagon, causing further price distortions. This behavior is common in asset bubbles and can be reinforced by the attention-grabbing nature of the information.
4. **Market Volatility and Inefficiencies**: Because noise traders react to salient but potentially irrelevant information, their actions can increase market volatility and lead to mispricing. Rational investors (or informed traders) may not always be able to correct these price distortions, as the actions of noise traders can dominate market movements, creating bubbles or crashes.

Measuring noise in financial information flow is critical to understanding the quality and reliability of data used in financial decision-making. Noise refers to random, irrelevant, or misleading information that can obscure the true signals within financial data. Here are some approaches that already exist to measure or quantify noise in financial information flow.

For modeling stock price fluctuations caused by noisy traders in Python we used the numpy and matplotlib pyplot libraries and we set a random seed for reproducibility, generated time points, generated a fundamental stock price trend (e.g., a steady upward trend) and added noisy trader effects (random fluctuations)(see pic. 1).

Graph 1

Stock price fluctuations caused by noisy traders.



Source: Developed by authors.

Biases in a trader's decision-making process

The last factor is the representation of biases in trader's decisions. We are considering only one group which is named Portfolio biases.

Portfolio biases refer to systematic deviations from optimal diversification in investors' portfolios. These biases can take many forms, such as:

- **Home bias:** The tendency for investors to hold a disproportionately large share of domestic assets.
- **Familiarity bias:** Preference for familiar assets, often from companies or sectors investors know well.
- **Risk aversion bias:** Overinvestment in safer, less volatile assets, even when riskier assets might provide higher returns.
- **Overconfidence Bias:** Overconfidence bias occurs when traders overestimate their knowledge, skills, or ability to predict market movements.
- **Herding Behavior:** Herding occurs when investors follow the actions of others rather than making independent decisions based on their own information or analysis.

Rational inattention can help explain why portfolio biases occur. Since investors have limited cognitive resources, they may rationally choose to focus only on certain types of information when making investment decisions. Here are a few ways they interrelate:

1. **Home Bias and Information Costs:** Investors might exhibit *home bias* because they find it easier or less costly to gather information about domestic markets than foreign ones. As a result, they are more "attentive" to local market conditions and allocate a larger share of their portfolio to domestic assets. From the perspective of rational inattention, focusing on local markets minimizes the cognitive and informational cost.
2. **Familiarity Bias and Simplified Decision-Making:** Investors might prefer familiar companies or sectors because these require less cognitive effort to evaluate. For example, someone who works in the tech sector may pay more attention to tech stocks because the cost of processing information about them is lower. Rational inattention explains this as an efficient way of managing limited information-processing capacity.

3. Risk Aversion and Information Avoidance: Risk-averse investors might avoid paying attention to complex or uncertain financial information (e.g., about emerging markets or speculative assets), leading to biases toward safer assets. This avoidance can be rational if the cost of processing uncertain information outweighs the perceived benefits of diversification.

4. Overconfidence Bias Overconfident noise traders often make excessive trades, underestimating the risks involved and overestimating their ability to time the market. They are more likely to act on "noisy" or irrelevant information, believing they can capitalize on it, leading to increased market volatility. Their actions are often driven by recent price movements or media hype rather than careful analysis of fundamentals. Overconfident noise traders can inflate bubbles or worsen crashes as they aggressively buy or sell assets, ignoring the underlying risks or overreacting to superficial signals.

5. Herding Behavior Noise traders are particularly prone to herding because they are often swayed by the actions of the majority or by salient information in the media. When many traders act in the same direction (e.g., buying during a bull market or selling during a crash), noise traders amplify these trends by jumping on the bandwagon. Herding can lead to bubbles or crashes, as large groups of traders move in the same direction, pushing prices far beyond their fundamental values.

According to the above-presented models and theories we propose an experimental model of trader's behavior under uncertainty in the system of portfolio biases and time perspective.

The collective impact of individual trader biases, combined with varying levels of market news informativity, can significantly affect broader market dynamics:

- **Market Overreaction or Underreaction:** Overreaction occurs when traders respond too aggressively to new information, causing asset prices to overshoot their true value. This is often driven by **overconfidence** and **herding**. Conversely, underreaction occurs when traders fail to adjust their portfolios sufficiently in response to news, which can happen due to **anchoring** or **confirmation bias**.
- **Increased Volatility:** When news is rapidly disseminated, traders with different biases interpret and act on it in varying ways. This asynchronous processing of news can increase market volatility, especially in the short term.
- **Inefficient Markets:** Behavioral biases and the misinterpretation of market news can lead to price distortions and inefficiencies, challenging the assumption of efficient markets (as posited by the Efficient Market Hypothesis). Prices might deviate from their intrinsic value for extended periods due to traders' psychological tendencies.

Bias Modeling

Bias modeling in decision-making process of noisy traders can significantly enhance the general understanding of the Adaptive Market Hypothesis (AMH). Advanced models can describe the historic impact of all the above-mentioned biases on market state while the predictive power of some models provides valuable feedback to market participants, not limited to noisy traders, i.e., funds utilizing hedging strategies.

In this research, the observed modeling approaches are the Statistical approach and Machine Learning (ML) approach. The statistical approach mainly employs simple regressive models often requiring careful selection of describing features of the objective – in this case the type of the bias. The ML approach often referred to as a "black box" model, due to the complexity of the interpretation of the underlying mechanisms by the practitioners, is far more powerful (Arrieta et al., 2020). Machine Learning is a subfield of Artificial Intelligence (AI) which utilizes advanced algorithms and statistical techniques to capture relations and recognize complex patterns in data. The rapid growth of the adoption of ML models for various financial market-related tasks sets an incentive to further explore the approach for behavioral finance (Henrique, Sobreiro, & Kimura, 2019).

In their research, Silva, Tabak, and Ferreira (2019), compare the performance of both the Statistical and Machine Learning approaches for the prediction of stock returns depending on the sentiment of the investors. The research concludes a superior performance by Machine Learning approach. However, the research explores only the traditional decision tree-based Machine Learning techniques such as Random Forest, Adaboost, XGBoost, and LightGMB, the benchmark being Logistic regression. While the decision tree-based models are powerful and established tools for financial tasks, they still require some degree of feature engineering to yield the best results and avoid overfitting (Abdelouahed, Abla, Asmae, & Abdellah, 2024).

The research aims to reveal new insights from the decision-making processes of noisy traders considering their portfolio biases; hence further and more sophisticated Machine Learning approach is proposed. Deep Learning (DL) approach extends Machine Learning approach by adding more data processing layers - resulting in complex model architectures - each capable of capturing and learning features without the necessity of profound initial feature engineering.

Given the research object the main two model architectures worth exploring are Convolutional Neural Networks (CNN), notable in the field of image processing for pattern recognition, and Recurrent Neural Networks (RNN), initially created for text processing tasks and later recognized and adopted for time series analyses with a noteworthy architecture modification - Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU). These two model architectures can be used for in-depth analyses of behavioral patterns (biases) and their changes and adaptations over time and uncertainty (Fazzari, Romano, Falchi, & Stefanini, 2024).

Conclusion

The research introduces a new perspective on analyzing trader behavior by integrating a model that combines portfolio biases with time perspective to simulate trader responses under uncertainty. This approach goes beyond traditional views by emphasizing how individual biases and market news informativity jointly shape market dynamics, contributing to phenomena like market overreaction, underreaction, and increased volatility. The study's proposed experimental model thus offers an innovative framework for observing how noisy traders' biases influence market efficiency and pricing. This model highlights the role of psychological and behavioral factors in adaptive markets, suggesting that market inefficiencies and price distortions arise not only from information gaps but also from complex bias-driven behaviors that amplify volatility and impact market equilibrium over time. We propose to examine Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) as architectures worth exploring for in-depth analyses of behavioral patterns (biases) and their changes and adaptations over time and uncertainty.

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