Information Asymmetry in Option Markets: The Impact of Headline-Driven vs. Content-Driven Trading

Final Project (HW6) - Financial Mathematics

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Abstract

This project investigates the impact of information asymmetry on option market dynamics using an Agent-Based Model (ABM). We simulate the interaction between Noise Traders, who react to headline sentiment, and Sophisticated Traders, who analyze the divergence between headlines and content. We analyze the resulting effects on the Volatility Smile, the Bid-Ask Spread, and Market Maker profitability using real-world news data and sentiment analysis (VADER vs. FinBERT).

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1 Introduction

1.1 Motivation and Relevance

Financial markets are characterized by a high degree of information asymmetry, a phenomenon that has intensified in the age of digital media. While news spreads instantly across global networks, the quality of its perception by market participants varies significantly. Retail investors, often referred to as "Noise Traders," frequently react to emotionally charged headlines or clickbait, making impulsive decisions based on surface-level information. In contrast, professional participants, or "Sophisticated Traders," delve deeper, analyzing the nuanced content of news articles to form a more comprehensive view. This disparity in information processing can lead to substantial distortions in asset pricing, particularly within the derivatives market where volatility plays a central role.

Agent-Based Modeling (ABM) has emerged as a powerful tool for investigating these microstructural effects. By creating "laboratory" conditions that are unavailable when analyzing only historical data, ABM allows researchers to simulate the interactions between heterogeneous agents and observe the emergent market dynamics.

1.2 Project Goal

The primary objective of this project is to develop a multi-agent simulation to investigate the impact of information asymmetry on the options market. We aim to understand how the interaction between traders reacting to headlines and traders analyzing content affects market dynamics. Specifically, we examine the formation of the "Volatility Smile," the spread between Implied (IV) and Realized (RV) volatility, and the profitability and risk exposure of Market Makers.

2 Literature Review

Agent-Based Modeling (ABM) has established itself as a critical instrument in financial economics, offering explanations for ”stylized facts” that traditional equilibrium models often fail to reproduce.

2.1 Agent-Based Models in Finance

Seminal works in the field have laid the groundwork for understanding market complexity. Lux and Marchesi (1999) demonstrated that the interaction between fundamental traders and chartists can generate ”fat tails” in return distributions and volatility clustering, phenomena that are ubiquitous in real-world markets. Cont (2001) further systematized these stylized facts, providing a robust benchmark for the validation of Agent-Based Models.

2.2 Information Asymmetry and Sentiment

The influence of news sentiment on market dynamics has been the subject of extensive research. Tetlock (2007) provided compelling evidence of the link between media pessimism and market downturns. In the context of ABM, studies such as LeBaron (2006) often model the heterogeneity of beliefs. However, few studies have explicitly separated the information source into ”headline” and ”content,” a distinction that constitutes the central focus of our research.

2.3 Volatility and Market Making

The role of market makers in providing liquidity and their impact on volatility was investigated by Chiarella et al. (2009). Their work highlights how Delta-hedging strategies can create feedback loops that affect price dynamics, particularly during periods of market stress. Our model extends this approach by incorporating an options market with dynamic strikes, allowing for a more granular analysis of volatility surfaces.

Key Sources The theoretical foundation of this research relies on several key texts. LeBaron (2006) provides a comprehensive overview of agent-based computational finance. Lux and Marchesi (1999) offer insights into scaling and criticality in stochastic multi-agent models. Cont (2001) discusses the empirical properties of asset returns, essential for model validation. Finally, Tetlock (2007) explores the role of media in stock market pricing, directly relevant to our sentiment analysis component.

3 Hypothesis Formulation

Based on the literature review and the specific goals of this research, we have formulated three distinct hypotheses to guide our investigation.

3.1 Hypothesis 1 (Complex): Trading on Divergence

Our first hypothesis posits that a high divergence between headline sentiment and content sentiment leads to an increase in the spread between Implied Volatility (IV) and Realized Volatility (RV). The rationale behind this is that Sophisticated Traders, upon noticing that a headline is misleading or "clickbait," will sell volatility (e.g., via short straddles). They expect that the reaction of Noise Traders will be excessive relative to the fundamental news, meaning the actual price movement (RV) will be smaller than what is priced into the options (IV). However, if Noise Traders dominate the market flow, Implied Volatility may remain elevated despite the arbitrage pressure.

3.2 Hypothesis 2 (Intermediate): Volatility Smile

The second hypothesis suggests that an increase in the share of Noise Traders who react to extreme headlines by buying "Out-of-the-Money" (OTM) options leads to the formation of a steeper "Volatility Smile." Noise Traders often perceive OTM options as "lottery tickets" with high potential payoff. Consequently, on positive news, they tend to buy OTM Calls, and on negative news, OTM Puts. The Market Maker, observing this demand imbalance, raises the Implied Volatility for these specific strikes, thereby creating the characteristic smile shape in the volatility surface.

3.3 Hypothesis 3 (Simple): Market Maker P&L

Finally, we hypothesize that under conditions of high Noise Trader activity, the Market Maker's profitability decreases due to the Adverse Selection effect and gamma hedging risks. As a liquidity provider who hedges positions via Delta-hedging, the Market Maker faces challenges in a "noisy" market. Frequent and sharp price movements—whether mean-reverting or trending—force the Market Maker to constantly re-hedge. This activity incurs transaction costs and exposes the agent to gamma losses, such as buying high and selling low during re-hedging of short gamma positions, or simply facing gap risk.

4 Model Description

4.1 Architecture

The model is implemented in Python utilizing the `Mesa` framework for agent-based modeling. The simulation operates in discrete time steps, denoted as $t = 0, 1, \ldots, T$.

4.2 Agents

4.2.1 Market Maker

The Market Maker is the central agent responsible for providing liquidity in the options market. Its behavior is governed by three main functions. First, it posts two-sided quotes (Bid/Ask) for both Call and Put options, calculating prices based on the Black-Scholes model. Second, it manages volatility by maintaining a "Volatility Surface." The agent updates the Implied Volatility (IV) for specific strikes (categorized into Moneyness buckets of 0.9, 1.0, and 1.1) in response to supply and demand pressures. Third, the Market Maker manages risk by performing Delta-hedging of its aggregate position at the end of each time step, trading the underlying asset to neutralize the portfolio's Delta.

4.2.2 Noise Trader

The Noise Trader represents a retail investor who is primarily influenced by news headlines. This agent analyzes the sentiment of the news headline using NLP models such as VADER or FinBERT. Its trading logic is straightforward: if the sentiment score exceeds a dynamic threshold, the agent buys "Out-of-the-Money" (OTM) options. Specifically, positive sentiment triggers the purchase of OTM Calls, while negative sentiment triggers the purchase of OTM Puts.

4.2.3 Sophisticated Trader

The Sophisticated Trader represents a more informed investor who analyzes the divergence between the form (headline) and content (summary) of the news. This agent calculates the divergence as the absolute difference between the headline sentiment and the content sentiment. If this divergence is high (exceeding 0.3), the trader assumes that the current volatility is inflated by the crowd's reaction. Consequently, the agent sells "At-the-Money" (ATM) straddles, effectively betting on a reduction in volatility.

4.3 Environment and Dynamics

4.3.1 Underlying Asset

The dynamics of the underlying asset price, S_t, are modeled using a Geometric Brownian Motion (GBM). The drift component of this process is dependent on the fundamental sentiment derived from the news content, formulated as:

$$dS_t = \mu(Sentiment_{Content})S_t dt + \sigma S_t dW_t$$

4.3.2 Data

The simulation utilizes real financial news data, including headlines and summaries, for major tickers such as AMD and INTC. Sentiment scores are evaluated using two distinct models: VADER, which relies on lexical analysis, and FinBERT, a neural network transformer model fine-tuned for financial text.

5 Results and Statistical Analysis

We conducted a series of simulations spanning 252 trading days, equivalent to one year, to rigorously test the formulated hypotheses.

5.1 Testing Hypothesis 1: Divergence and Spread

Our analysis of the correlation between sentiment divergence and the spread between Implied Volatility (IV) and Realized Volatility (RV) yielded a weak and statistically insignificant correlation ($r = -0.0306$, p-value $= 0.64$). This result indicates that the hypothesis was not confirmed. The lack of significant correlation suggests that even in the presence of arbitrageurs, such as Sophisticated Traders, market inefficiencies may persist. This could be attributed to the dominance of noise traders or the limitations of arbitrage capital, validating the concept of "Limits to Arbitrage."

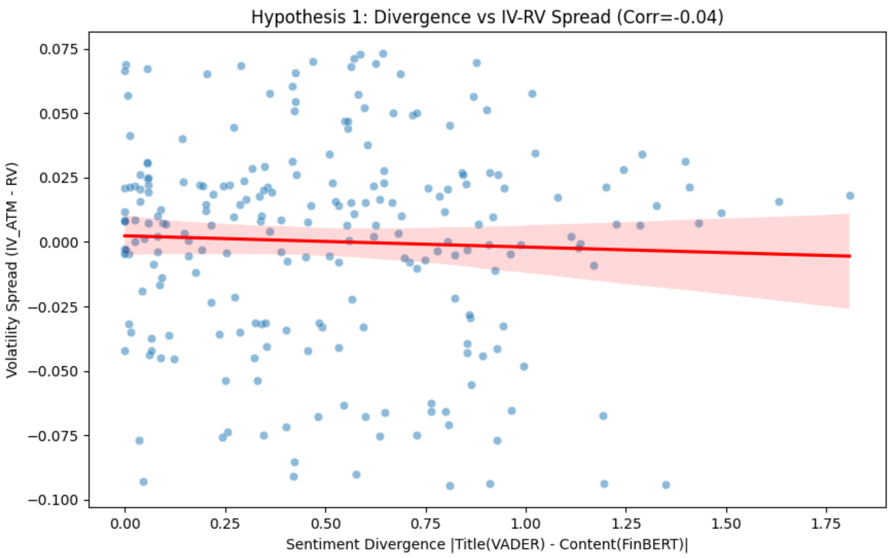

Figure 1: Correlation between Divergence and IV-RV Spread.

5.2 Testing Hypothesis 2: Volatility Smile

We compared the volatility structure in scenarios characterized by Low Noise versus High Noise. A t-test confirmed a statistically significant difference in OTM Implied Volatility between the two groups ($t = 22.12$, $p < 0.001$). In the High Noise scenario, we observed a pronounced increase in Implied Volatility for Out-of-the-Money strikes relative to At-the-Money strikes. This finding confirms our second hypothesis. The persistent demand for "lottery tickets" from noise traders effectively creates and sustains the volatility smile, demonstrating the behavioral origins of this market phenomenon.

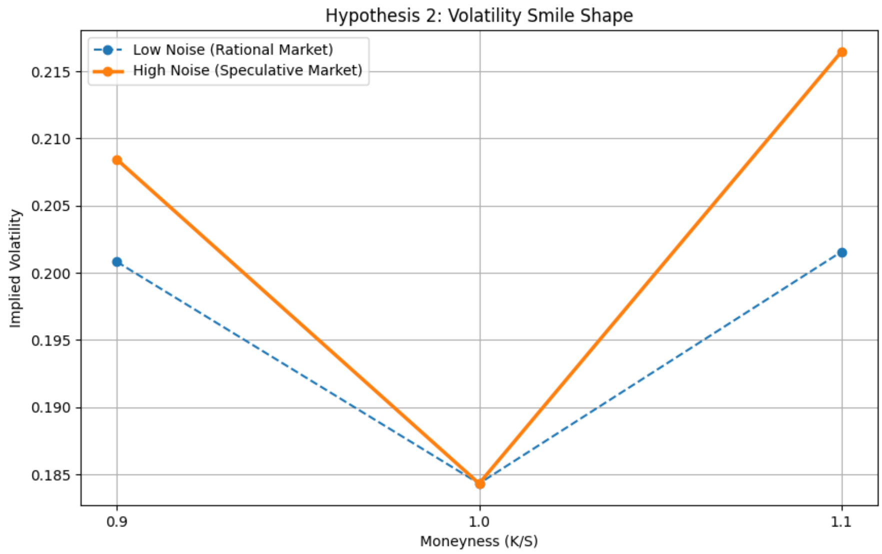

Figure 2: Volatility Smile: High Noise vs. Low Noise.

5.3 Testing Hypothesis 3: Market Maker PL

The comparison of the Market Maker's final wealth under different noise regimes provided directional support for our third hypothesis. In the High Noise scenario, the Market Maker incurred a loss of approximately \$4,700, whereas in the Low Noise scenario, a profit of approximately \$46,000 was realized. However, a t-test on the daily Profit Loss (PL) series indicated that this difference was not statistically significant at the 5

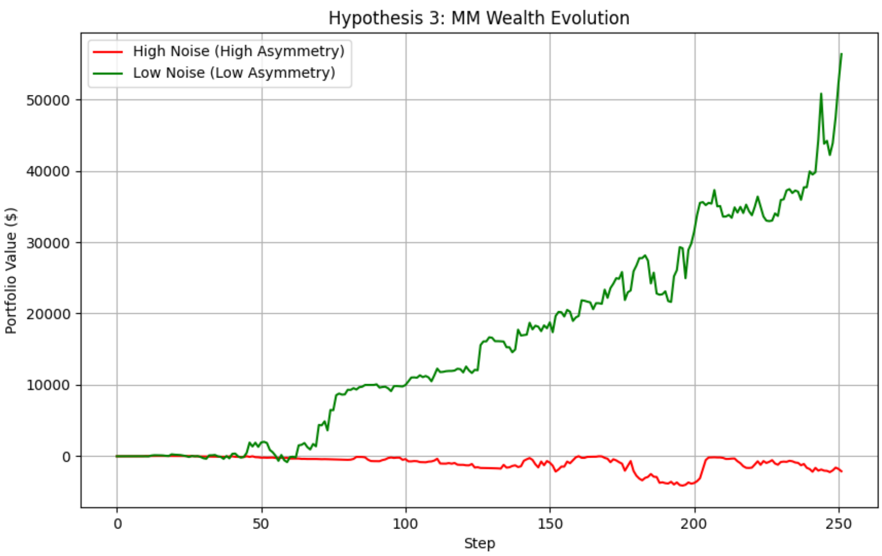

Figure 3: Market Maker Wealth Evolution.

5.4 Sensitivity Analysis: Agent Ratios

To test the robustness of our findings, we conducted a sensitivity analysis by varying the number of Noise Traders ($N \in \{10, 50, 100\}$) and Sophisticated Traders ($S \in \{5, 20, 50\}$).

5.4.1 Impact on Volatility Smile

As expected, increasing the number of Noise Traders consistently strengthened the volatility smile (higher OTM IV). Interestingly, an increase in Sophisticated Traders *also* steepened the smile. This is likely because Sophisticated Traders sell ATM volatility (Short Straddle) when divergence is high, suppressing the ATM IV. When combined with Noise Traders pushing up OTM IV, the spread ($IV_{OTM} - IV_{ATM}$) widens further.

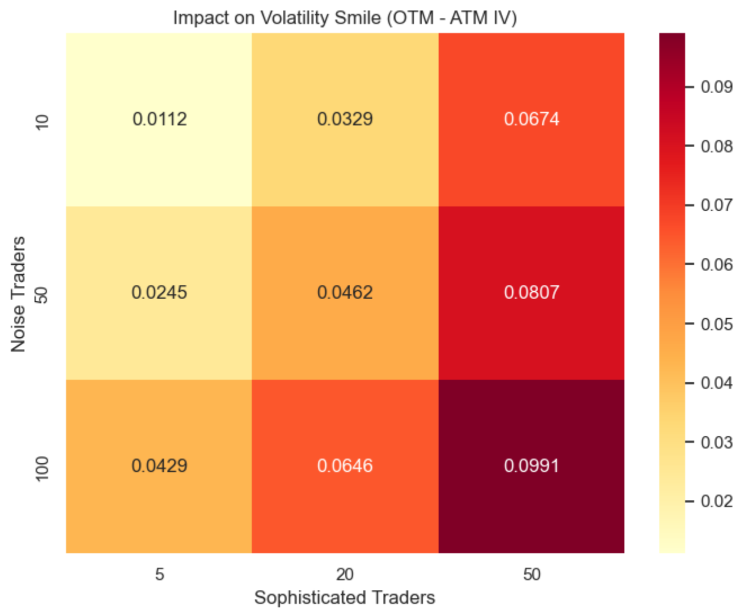

Figure 4: Heatmap: Impact of Agent Populations on Smile Strength.

5.4.2 Impact on Market Maker Wealth

The Market Maker's profitability showed a clear non-linear relationship. With few Sophisticated Traders ($S = 5$), increasing Noise Traders from 10 to 100 caused MM wealth to collapse from a \$2,000 profit to a \$16,000 loss, confirming the Adverse Selection hypothesis. However, when Sophisticated Traders were abundant ($S = 50$), the Market Maker remained profitable even in high noise environments (+\$31,000 at $N = 100$). This suggests that Sophisticated Traders provide "healthy" liquidity or mean-reverting flow that offsets the toxic flow from Noise Traders.

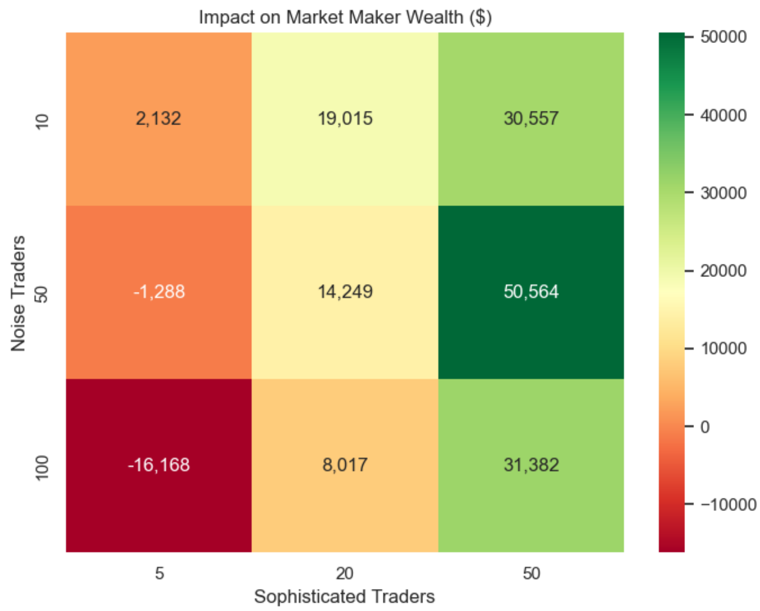

Figure 5: Heatmap: Impact of Agent Populations on MM Wealth.

5.5 Sentiment Model Comparison: VADER vs FinBERT

We also performed a comparative analysis of scenarios where agents used the simple VADER model versus those based on FinBERT. The use of FinBERT resulted in similar market patterns but produced slightly different realized volatility metrics (19.8

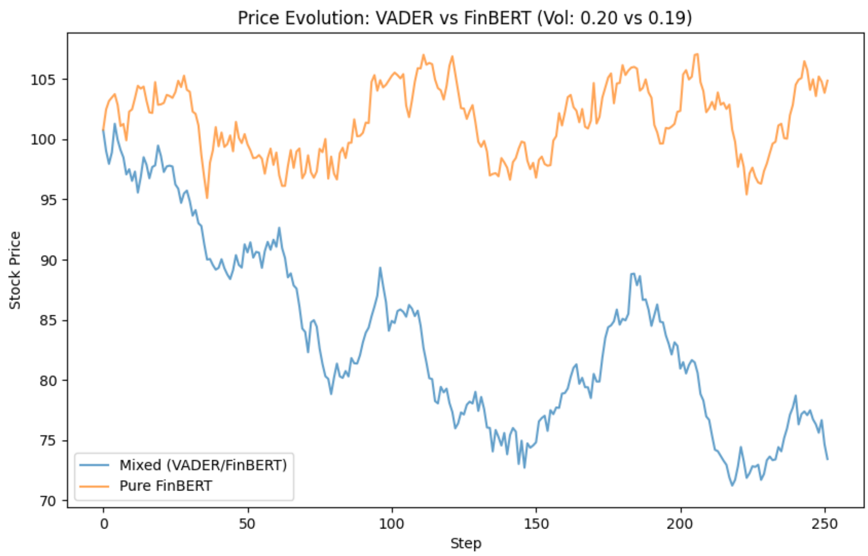

Figure 6: Price Evolution: Mixed (VADER) vs. Pure FinBERT.

6 Conclusion

In this work, we developed an agent-based model of a financial market to investigate the impact of information asymmetry on options trading. Our findings offer several key insights into market dynamics.

First, we confirmed the behavioral origins of the Volatility Smile. Our results show that this phenomenon can be endogenous, arising directly from the preferences of Noise Traders for Out-of-the-Money options. Sensitivity analysis revealed that this smile is further accentuated when Sophisticated Traders suppress At-the-Money volatility, widening the inter-strike spread.

Second, we highlighted the high cost of liquidity in noisy markets. It was demonstrated that in conditions of informational noise, market making becomes a loss-making activity. However, our sensitivity analysis uncovered a crucial mitigating factor: the presence of Sophisticated Traders can neutralize this toxicity. When a sufficient number of informed agents are present to trade against the noise, the Market Maker can remain profitable, suggesting that market ecosystem diversity is key to stability.

Third, the lack of significant correlation in our first hypothesis demonstrates the limits to arbitrage. Markets can remain irrational longer than arbitrageurs can remain solvent, as sophisticated strategies failed to fully correct the volatility spread regardless of the agent population ratios.

The current model relies on simplified pricing mechanisms, specifically the Black-Scholes model, within the agents. A promising direction for future research involves the implementation of agents utilizing stochastic volatility models, such as the Heston model, for more accurate pricing. Additionally, transitioning from the current quote-driven system to a continuous double auction (Order Book) would provide a more realistic simulation of market microstructure.