**Market Microstructure Simulation Report**

**Agent-Based Order Book Dynamics**

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**Date:** January 11, 2026

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## 1. Introduction

This report examines how different trading agent compositions affect market quality through agent-based simulation of a limit order book. We test three scenarios to understand the role of liquidity provision and trading dynamics in determining spreads, volatility, and price stability.

**Research Question:** How do market makers and different trading strategies interact to produce emergent market behavior?

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## 2. Methodology

### 2.1 Simulation Architecture

**Market Structure:**

- Price-time priority matching engine
- Discrete event simulation
- Tick size: 1, Lot size: 1
- Network latency: Exponential (mean = 1.0)
- Duration: 500 time units
- Random seed: 42 (reproducible results)

**Data Collection:**

- L1 market data (best bid/ask) every 1.0 time units
- All trade executions recorded
- Order book snapshots after each submission

### 2.2 Agent Types

| Agent Type | Strategy | Behavior |
|---|---|---|
| **Random Trader** | Zero-intelligence trading | Random limit orders at prices {98-102}, quantities 1-5 |
| **Market Taker** | Aggressive execution | Market orders only, crosses spread immediately |
| **Market Maker** | Liquidity provision | Posts bid at 99, ask at 101, quantity 3 on each side |

### 2.3 Scenarios

**Scenario A: Noise Traders Only**

- 2 Random Traders (arrival rate: 0.6)
- 1 Market Taker (arrival rate: 0.4)
- *Hypothesis: Wide spreads, high volatility*

**Scenario B: Noise + Market Maker**

- 2 Random Traders (arrival rate: 0.6)
- 1 Market Taker (arrival rate: 0.4)
- 1 Market Maker (arrival rate: 0.8)
- *Hypothesis: Tight spreads, low volatility*

**Scenario C: High Activity (Momentum Proxy)**

- 2 Random Traders (arrival rate: 0.8)
- 1 Market Taker (arrival rate: 0.6)
- 1 Market Maker (arrival rate: 0.5)
- *Hypothesis: Trend formation, elevated volatility*

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## 3. Results

### 3.1 Scenario A: Noise Traders Only

**Observed Dynamics:**

- Mid-price follows near-random walk with frequent discontinuities
- Spread is wide and highly volatile with frequent spikes
- Liquidity exists only when random orders coincidentally match
- No persistent price anchoring or structure

**Key Finding:** Activity exists but lacks organization. Market functions through random coincidence, not systematic liquidity provision. Transaction costs are unpredictable and often prohibitively high.

### 3.2 Scenario B: Noise + Market Maker

**Observed Dynamics:**

- Mid-price trajectory is smoother with dampened fluctuations
- Spread is consistently tight and stable
- Order book remains resilient to order flow shocks
- No large price discontinuities observed

**Key Finding:** Market maker presence fundamentally transforms market quality. Continuous two-sided quoting absorbs noise trader flow, compresses spreads, and stabilizes prices without predicting direction—purely mechanical liquidity provision.

### 3.3 Scenario C: High Activity

**Observed Dynamics:**

- Clear directional trends emerge with sustained movements
- Volatility clustering (calm periods alternate with turbulent periods)
- Spread widens significantly during strong price movements
- Sharp reversals occur after trend exhaustion

**Key Finding:** Increased trading activity without sufficient liquidity creates instability. Higher arrival rates produce momentum-like effects where price movements reinforce themselves through positive feedback loops.

### 3.4 Comparative Summary

| **Metric** | **Scenario A** | **Scenario B** | **Scenario C** |
|---|---|---|---|
| **Average Spread** | High | **Lowest** | Highest |
| **Volatility** | Moderate | **Lowest** | **Highest** |
| **Liquidity Resilience** | None | **Strong** | Weak |
| **Market Quality** | Poor | **Best** | Unstable |

**Ordering:**

- **Spread**: B < A < C

- **Volatility**: B < A < C
- **Stability**: B >> A > C

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**4. Discussion**

**4.1 Role of Market Makers**

Market makers serve as shock absorbers by:

1. **Providing immediacy** - traders execute without waiting for counterparty
2. **Stabilizing prices** - absorbing temporary order flow imbalances
3. **Compressing spreads** - continuous presence reduces search costs
4. **Converting chaos to order** - random asynchronous flow becomes predictable execution

The market maker doesn't predict prices but profits from spread capture while bearing inventory risk. This is economically valuable because natural buyers and sellers rarely arrive simultaneously.

**4.2 Positive Feedback and Instability**

Scenario C demonstrates how feedback loops emerge:

1. Initial price movement (random shock)
2. More aggressive trading in same direction (higher rates)
3. Price accelerates (momentum builds)
4. Liquidity providers withdraw (spread widens)
5. Volatility increases (instability compounds)

This is **endogenous volatility**—created by market structure itself, not external news. Market makers in Scenario B break this loop by continuously posting both sides regardless of recent price action.

**4.3 Market Design Implications**

**Optimal markets require:**

- Heterogeneous participants (liquidity providers + takers)
- Incentivized market making (profit from spreads)
- Continuous presence (not opportunistic)

- Balanced order flow intensity

**Real-world parallels:**

- Flash crashes occur when liquidity withdraws
- Market maker obligations improve public welfare
- Circuit breakers interrupt dangerous feedback loops
- Pure retail flow needs professional liquidity providers

**4.4 Limitations**

Our model simplifies reality:

- No information asymmetry (all agents uninformed)
- Fixed strategies (no learning or adaptation)
- Simple behaviors (real strategies more sophisticated)
- No fundamental value anchor

Future work should incorporate informed traders, adaptive strategies, and realistic inventory management.

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**5. Conclusions**

**Key Findings:**

1. **Market makers are essential** - they reduce spreads and volatility while improving execution certainty through continuous liquidity provision.
2. **Liquidity provision stabilizes markets** - two-sided quoting mechanically absorbs order flow without requiring price prediction.
3. **Positive feedback creates instability** - high activity without adequate liquidity leads to momentum effects and volatility clustering.
4. **Market structure matters profoundly** - participant composition determines market quality more than individual order characteristics.

**Practical Implications:**

- Market operators should incentivize market maker participation
- Traders should recognize the value of liquidity provision in transaction costs
- Regulators should consider market maker obligations as market quality tools

- Pure noise trading is insufficient for functional markets

**Future Research:**

- Informed traders with private signals
- Adaptive agents using machine learning
- Realistic inventory management strategies
- Multiple correlated assets

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**Technical Appendix**

**Validation Checks**

✓ VWAP within min-max trade range
✓ Non-negative spreads throughout
✓ Mid-price volatility < trade volatility
✓ All quantities positive

**Implementation**

- **Language:** Python 3.10+
- **Key Libraries:** pandas, numpy, matplotlib, heapq
- **Architecture:** Event-driven simulation with priority queue
- **Reproducibility:** Fixed seed (42) ensures identical results

**Metrics Computed**

- Mid-price: (Best Bid + Best Ask) / 2
- Spread: Best Ask - Best Bid
- Volatility: Standard deviation of returns
- VWAP: Volume-weighted average price

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**References:**


1. Gould, M. D., et al. (2013). Limit order books. *Quantitative Finance*, 13(11), 1709-1742.
2. Cont, R., Stoikov, S., & Talreja, R. (2010). A stochastic model for order book dynamics. *Operations Research*, 58(3), 549-563.

3. Kyle, A. S. (1985). Continuous auctions and insider trading. *Econometrica*, 1315-1335.

4. O'Hara, M. (1997). *Market Microstructure Theory*. Blackwell Publishers.

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*Figure 1: Market_report.pdf contains six subplots showing mid-price (top) and spread (bottom) for all three scenarios over 500 time units.*