# Computational Models of Algorithmic Trading in Financial Markets

# (Doctoral Consortium)

Elaine Wah
Supervisor: Michael P. Wellman
Computer Science & Engineering
University of Michigan
2260 Hayward St
Ann Arbor, MI 48109-2121
ewah@umich.edu

## ABSTRACT

In today's financial markets, algorithmic trading, the use of quantitative algorithms to automate the submission of orders, is responsible for the majority of trading activity. To better understand the societal implications of algorithmic trading, I construct computational agent-based models comprised of investors and algorithmic traders. I examine two overlapping types of algorithmic traders: high-frequency traders, who exploit speed advantages for profit, and market makers, who facilitate trade and supply liquidity by simultaneously maintaining offers to buy and sell. I employ simulation and empirical game-theoretic analysis to study trader behavior in equilibrium, that is, when all traders best-respond to their environment and other agents' strategies. I focus on the impact of algorithmic trading on allocative efficiency, or overall gains from trade, and the potential for a call market, in which orders are matched to trade at periodic intervals, to mitigate the latency advantages of high-frequency traders.

## Categories and Subject Descriptors

J.4 [**Social and Behavioral Sciences**]: Economics

## Keywords

Agent-based simulation; allocative efficiency; frequent call market; high-frequency trading; market making

## 1. INTRODUCTION

Algorithmic trading, or the use of automated computer algorithms to submit orders to buy or sell in financial markets, has dominated financial news headlines in recent years. From the "Flash Crash" on May 6, 2010, to trading firms accidentally flooding the market with hundreds of orders[1] and exchanges shutting down for hours due to technological glitches[2], the problems in today's financial markets have come under greater public scrutiny with the publication in April 2014 of *Flash Boys* by Michael Lewis [2]. *Flash Boys* tells the story of IEX, a trading venue designed specifically to deter speed-advantaged algorithmic traders from exploiting investors. Proponents of these high-speed traders posit that such activity reduces trading costs for market participants, while others argue that these traders manipulate the market and harm investors. There is no consensus on exactly what effects these strategies have, and a systematic research program to better understand the effects of algorithmic trading in financial markets is clearly necessary.

Previous work on the effects of algorithmic trading has relied primarily on either analytical models or examination of historical data. Historical market data alone is insufficient as it cannot be used to explore the impact of modifying agent strategies or the mechanisms by which markets match orders to trade. Analytical models can capture basic aspects of stock market structure. However, such models cannot specify the timing of event occurrences, such as the propagation of information between markets and participants. Such interactions between multiple entities are path-dependent and difficult to express in an analytical form.

Questions about the effects of algorithmic trading are inherently computational due to the nature of the trading algorithms involved and the electronic systems in place for processing and matching orders. Indeed, algorithmic traders are prime examples of intelligent agents: they are highly responsive to changes in their environment, they often learn from historical performance, and they direct their activity towards achieving an objective (in this case, maximizing profit). The study of the societal implications of these intelligent systems—within the economic domain of the U.S. equities market—is therefore extremely well-suited for a computational approach. As such, I employ agent-based modeling and simulation to capture the interactions between traders in financial markets. Agent-based modeling allows the specification of interactions without the need for oversimplifying assumptions, as well as the ability to specify agent objectives individually rather than in aggregate. Simulation eliminates reliance on historical data, which is generally inadequate

[1] `http://www.reuters.com/article/2012/08/01/us-usa-nyse-tradinghalts-idUSBRE8701BN20120801`

[2] `http://dealbook.nytimes.com//2013/08/29/nasdaq-blames-a-surge-of-data-for-trading-halt`

**Appears in:** *Proceedings of the 14th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2015), Bordini, Elkind, Weiss, Yolum (eds.), May 4–8, 2015, Istanbul, Turkey.*

for answering counterfactual questions, and facilitates exploration of a range of environments.

By modeling financial markets computationally, I can readily explore both the effects of algorithmic trading in varying market configurations as well as the possible impact of new regulation. Insight into these effects is of great interest to regulators and policymakers, as it has the potential to better inform financial policy and regulatory decisions. A more comprehensive understanding of the relationship between algorithmic trading and market mechanisms—as well as their effects on market participants—is invaluable in the rulemaking process. By providing this insight, my dissertation work has the potential not only to help promote overall efficiency, but also to shape future regulation on market structure in order to ensure the safety, soundness, and integrity of our financial markets.

## 2. ALGORITHMIC TRADING

I focus on two overlapping types of algorithmic trading, high-frequency trading and market making. High-frequency trading, or HFT, involves the exploitation of latency advantages for profit, where latency is the time needed to receive, process, and act upon new information. There is no formal regulatory definition of HFT, but general attributes include high daily trading volume and extremely short holding periods (on the order of microseconds) [6]. High-frequency traders gain latency advantages through various methods, such as co-location, in which firms place their computers as close to an exchange's servers as possible. Many HFTs also pay for direct feeds in order to receive market data and market-moving information faster than other traders. Firms may spend millions of dollars to reduce latency only to be superseded by technology improvements that shave off additional milliseconds, as in the case of Spread Networks' fiber optics cable, which was deprecated less than two years after its completion by the introduction of a microwave network for information transmission [1]. Such activities have perpetuated a latency arms race in which HFTs compete to access and respond to information faster than their competitors; HFT firms spent an estimated $1.5 billion in 2013 on technology just to reduce latency [3]. Given it is responsible for over half of daily trading volume [4], HFT has the potential to have serious repercussions throughout the market.

The second category of algorithmic trading I study is market making. A market maker (MM) facilitates trade by simultaneously maintaining offers to buy and sell and supplies liquidity to the market. Liquidity refers to the availability of immediate trading opportunities at prices that reasonably reflect current market conditions. HFT and MM are not mutually exclusive, and many HFTs also act as market makers, rapidly submitting simultaneous buy and sell orders.

To better understand HFT and MM activity within financial markets, I construct computational models populated by investors and algorithmic traders. I have developed an agent-based simulation system to capture the interactions between traders and markets, which I use to run thousands of simulations at a variety of market settings and with different trader populations. I focus on the impact of algorithmic trading on allocative efficiency, which is a measure of how well markets distribute surplus (gains from trade) to participants. I also examine how orders are matched and cleared in the markets, as the effects of algorithmic traders are highly contingent upon the market clearing mechanisms in place.

### 2.1 High-frequency trading

Certain types of HFT strategies called latency arbitrage can exercise superior speed to exploit price disparities that arise from the fragmentation of trading across multiple markets. A periodic or frequent *call market* eliminates latency advantages of HFTs by hiding all submitted orders within each clearing interval, which ensures that standing offers cannot be readily picked off by incoming aggressive orders. This is in contrast to the *continuous double auction* (CDA) used in virtually all stock markets today, in which orders are matched as they arrive. I developed a two-market model to capture the behavior of certain types of HFT strategies called latency arbitrage, which exercise superior speed to exploit price disparities between exchanges. Using this model, I show that the presence of a latency arbitrageur degrades allocative efficiency, but switching to a call market eliminates the advantage of speed and promotes efficiency [5].

### 2.2 Market making

In another study, I elucidate the conditions under which the presence of MM can improve trading gains for non-MM investors. I employ empirical simulation-based methods to compare multiple environments comprised of a single CDA market populated by multiple background traders, both with and without a market maker. I analyze the performance of traders in equilibrium, when each player is strategically responding to others' strategies. My results demonstrate the general welfare benefits of market making: the presence of MM strongly tends to improve allocative efficiency. Not only is the MM itself profitable, but market making also boosts surplus of background traders, specifically for impatient investors in thin markets, with trading urgency captured by a shorter simulation length.

## 3. FUTURE WORK

One oft-raised question regarding the viability of call markets in a trading landscape dominated by continuous markets is whether traders are willing to forsake trading immediacy for a market less exploitable by speed-advantaged HFTs. To determine whether frequent call markets have the potential to coexist alongside CDA markets, I will also investigate the equilibrium behavior of investors who can choose to submit orders to either a frequent call market or a CDA.

## References


[1] J. Adler. Raging bulls: How Wall Street got addicted to light-speed trading. *Wired Magazine*, Aug. 2012.

[2] M. Lewis. *Flash Boys: A Wall Street Revolt.* W. W. Norton & Company, 2014.

[3] S. Patterson. High-speed stock traders turn to laser beams. *The Wall Street Journal*, February 2014.

[4] D. Schneider. The microsecond market. *IEEE Spectrum*, pages 66–81, June 2012.

[5] E. Wah and M. P. Wellman. Latency arbitrage, market fragmentation, and efficiency: A two-market model. In *14th ACM Conference on Electronic Commerce*, pages 855–872, 2013.

[6] M. Wheatley. We need rules to limit the risks of superfast trades. *Financial Times*, 2010.