University Name

Master's Thesis

Thesis Title

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A thesis submitted in fulfilment of the requirements
for the degree of Doctor of Philosophy

in the

Research Group Name
Department or School Name

November 2013

Declaration of Authorship

I, John Smith, declare that this thesis titled, 'Thesis Title' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
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Signed: _______________________________________

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"Thanks to my solid academic training, today I can write hundreds of words on virtually any topic without possessing a shred of information, which is how I got a good job in journalism."

Dave Barry

UNIVERSITY NAME (IN BLOCK CAPITALS)

Abstract

Faculty Name
Department or School Name

Doctor of Philosophy

Thesis Title

by John Smith

The Thesis Abstract is written here (and usually kept to just this page). The page is kept centered vertically so can expand into the blank space above the title too...

Acknowledgements

The acknowledgements and the people to thank go here, don't forget to include your project advisor...

Contents

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Abbreviations

HFT	**H**igh **F**requency **T**rader
ST	**S**low **T**rader
OB	**O**rder **B**ook
MM	**M**arket **M**aker

Physical Constants

Term	Explanation
ask price	
bid price	
fitness	
limit order	
market order	
liquidity	
order book	
share	A fraction of ownership of an asset, such as a stock
spread	
tick	
volatility	

Physical Constants

Symbol	Explanation
$\tau_{i,j}$	Time delay in rounds from agent i to market j. Note that $\tau_{i,j} = \tau_{j,i}$

Symbols

Symbol	Description	Unit
n_{rounds}	Number of simulation rounds	rounds
λ	Average number of ST orders per round	
	Number of initial orders in OB	10^4 orders
	Mean and standard deviation of MM spread	ticks
	Mean and standard deviation of MM order volume	stocks
	Mean and standard deviation of MM order length	rounds
	Mean and standard deviation of chartist window length	rounds
	Mean and standard deviation of chartist sensitivity	ticks
	Mean and standard deviation of chartist aggressiveness	ticks
	Mean and standard deviation of chartist order volume	stocks
	Mean and standard deviation of chartist trade frequency	rounds
	Short selling allowed	`false`
	n_{mm}	Number of HFT chartist agent
	n_c	Number of HFT chartist agent

asd

For/Dedicated to/To my…

Chapter 1

Model

1.1 Model

As explained in section 2, perhaps the most distinguishable aspect of high frequency trading is the speed with which agents can react to new market information.

In this work, we have tried emulate the asynchronous nature of a continuous auction by

The model consists a market and agents. Agents and the market communicate by exchanging messages which all arrive one or several rounds after they were issued. A complete simulation consists of the several consecutive rounds. In each rounds, some agents submit orders, while others wait for new market information. Order messages arrive at the order books, and trades are executed when prices match. The following sections will describe the model in detail.

1.2 Modeling delays

Although each round corresponds to a period of real-time, it is not particularly important to specify how long that period is. Instead, what matters is that there is a difference in speed between the agents. In other words, the important thing is that some agents are much faster than other agents. If one thinks of each round as a millisecond of real-time, one realizes that an agent simulating a human trader will require several thousands of simulation rounds to react to market news. On the other hand, fast algorithmic traders may only require a few rounds, making them several orders of magnitude faster than the slow traders.

This focus on the extremely

Another issue when simulating

1.3 Market components

Sending/receiving orders, supply liquidity

1.3.1 Regulations

1.3.2 Stocks

A stock is an asset which is traded on a market. The price of a stock is a mysterious thing. A stock is only worth as much as people are willing to pay for it, and the price at which is it traded thus goes up and down according to what beliefs people hold. In financial markets, every trader is supposed to have access to the same information. However, two traders might disagree on the meaning of some piece of information. The way in which a trader evaluates market information and reaches a conclusion on how to trade is called a strategy. While any function which takes some information relevant to the market as input and gives a decision of how to trade (or not trade at all) can be termed a strategy, it is useful to divide strategies into two broad categories. In the first category are strategies which are dubbed chartist strategies, which basically tries to extrapolate on the past price movements. In the other category are strategies which are based on some analysis of the true value of the stock, called the fundamental value. Not surprisingly, these are called fundamentalist strategies.

Whether or not one type of strategy is more accurate than the other, it is a fact that both types are employed by traders. Hence, a model of such an environment needs to simulate both a traded price and a fundamental price.

1.3.2.1 Fundamental price

A common way to model the development of the fundamental price is to use a stochastic random walk process. The idea is that, assuming that markets are efficient, any available information about the stock is already reflected in the fundamental price. When some news arrive, this will quickly cause the price to change according to the nature of the news, as rational traders act to adapt to the new situation. The justification for modeling this with a random walk is that, since the fundamental price already reflect whatever news is available, it will only change as new information is released. In other words, the fundamental price is independent of past information. Since new information is fundamentally unpredictable, a random walk model seems suitable.

The idea behind this is that

1.3.3 Messages

All communication between the market and agents is transmitted in messages. Each message has a transmission delay of τ

1.3.3.1 Orders

An order is an offer to buy or sell a specified number of shares at a certain price. Orders can be limit orders, which

1.3.3.2 Transaction receipts

1.3.3.3 Order cancellations

1.3.4 Order book

The order book is where the stock is traded. The book

One item of a stock is dubbed a share. The model contains a single stock which is traded on a single market. The minimum traded volume is one share.

Each order book contains the

On the other hand, a stock also represent a small fraction of

A common way to model such a fickle

A common model for the price development of the

1.3.4.1 Short selling

Although some market do allow deliberate short selling, this practice is not allowed in the simulation. That is, an agent is not allowed to place a sell order for more stock than it has in its portfolio at the time it places the order. However, due to the presence of delays, it can happen that an agent is required to deliver on a sell order for more stocks than it holds when notified of the order. A sequence of events which causes this to happen is illustrated on figure 1.1. The agent who is short is required to deliver the stocks, and thus goes into negative on its portfolio, and has to buy back the stocks before it can place further sell orders. Although the sequence of events shown in figure 1.1 may seem unlikely, it did in fact occur frequently, making it necessary to implement handling of this special case.

FIGURE 1.1: The HFT agent submits a sell order for 100 stocks, and another agent submits a price-matching buy order which fills the sell order. Before the transaction receipt reaches the seller, the seller decides to cancel the order, and submit another order at a different price. When the transaction receipt reaches the seller, the agent promptly sends out a cancellation of its second sell order, as it knows it cannot fulfill the order. However, before the cancellation reaches the market, a third agent fills the sell order, and a receipt is send to the seller who ends up being short.

1.4 Agents

The model contains three types of agents, each employing a different strategy. Since each strategy has several parameters which greatly impact the behavior of the agents, it is more natural to think of thee families of strategies.

1.4.1 Slow traders

The slow trader emulates human behavior

1.4.1.1 Arrival of orders

FIGURE 1.2: Slow trader order arrive randomly according to a Poisson process. The bars show the volume generated by slow traders. XXXWRITEMORE

1.4.2 Market makers

For the sake of simplicity, each market maker is only allowed to have one order at each side of the order book at the same time. The agent can therefore not stack orders on either side of the order book.

1.5 Simulation rounds

1.6 Implementation

Chapter 2

Parameter tuning

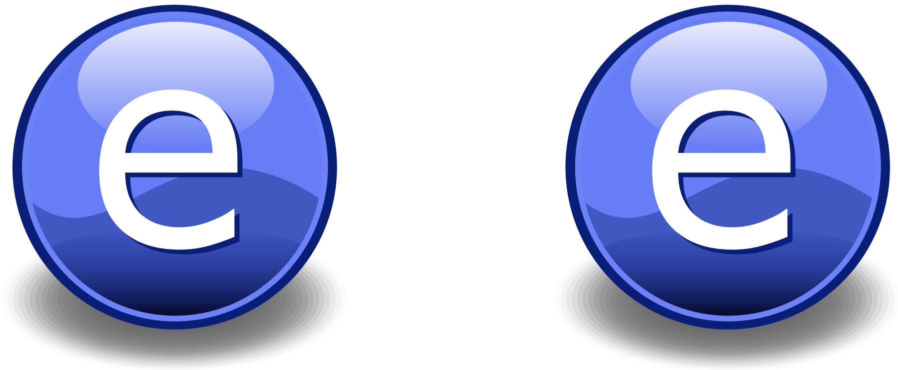
Chapter presented the model...XXX

The model has several parameters which must be selected carefully before the simulation can be used for XXX. The parameter tuning has two overall goals, which can be separated as follows.

First of all, the model must be calibrated such that it mimics the behavior of real markets. Since virtually every aspect of the simulation behavior depends on the values on the various parameters, these must be chosen carefully in order for the simulation to produce realistic behavior. An example of a simulation untuned parameters causing unrealistic behavior is given in figure 2.1a. Selecting realistic parameters is by far a simple task. First of all, it requires a way of quantifying the quality of each simulation. The choice of such a quantification is discussed in section 2.0.2. Secondly, there might be several different parameter configurations which produce seemingly realistic behavior, but do not correspond to a realistic market setting. An example for this is given in figure 2.1b, and section 2.0.3 briefly discusses this point. The second goal of the parameter tuning is to find parameters which promotes certain desirable behaviors. For instance, we might be interested in determining which parameters causes the traded price to stabilize faster after a shock to the fundamental price. Metrics for doing this is discussed in section 2.0.2

1. Fix some of the model parameters in order to reduce the search space for the optimization algorithm.

2. Use an optimization algorithm to find sets of parameters which yield realistic model behavior.



(A) Parameters causing unrealistic dynamics (B) Unrealistic parameters causing realistic dynamics

FIGURE 2.1: **Motivatoin for tuning:** the two

3. From the set of parameter combinations found by the optimization algorithm, remove the parameter combinations which are deemed to be unrealistic.

2.0.1 •

The large number of parameters makes it difficult to use most numerical methods due to the time it takes to evaluate a single set of parameters. Furthermore, the inherent randomness in the model means that the behavior of several simulations with the same set of parameters varies significantly. Therefore, two steps are required.

1. Reducing the number of parameters that need to be optimized
2. Run the simulation several times with each set of parameters and calculate summarizing statistics of the model behavior

The second point is trivial, and merely requires additional computation, but the first point requires us to consider which parameters can be fixed without making the model less realistic. to do this, we divide the parameters into three categories as follows:

Fixed across all experiments These are parameters such as market rules, and simulation settings,

Fixed for each experiment These are parameters which

Optimized for each experiment These are the

2.0.2 Defining parameter fitness

Furthermore, I did not have have access to

2.0.3 Filtering parameters

Without available data of the millisecond price movements of a stock in a real market it is difficult to create metrics for measuring the quality of a set of parameters. Instead, we

As mentioned earlier, it is not enough simply to define a fitness function which assigns high values to parameters causing realistic behavior. In addition, we need some way of

Instead of

1. The model must be calibrated such that it mimics the behavior of real markets.
2. The model

it must be calibrated. The calibration serves two in order to mimic the dynamics of real financial markets. Without calibration, the simulation will still produce an output, but the chances are high that

An overview of the model parameters is presented in the end of the thesis,

2.0.3.1 Fixed parameters

The number of rounds is fixed at 10^5 for all experiments. The simulation could easily be run for much longer, but due to the increased computational cost

2.1 Optimizing parameters

Appendix A

Appendix Title Here

Write your Appendix content here.