Continuous Double Auctions and Microstructure

Thesis by

Michael R. Alton

In Partial Fulfillment of the Requirements

for the Degree of

Doctor of Philosophy

California Institute of Technology

Pasadena, California

Submitted May 18, 2009

Acknowledgements

I would first like to thank my undergraduate advisors: Robert Fogel, Victor Lima and Javier Birchenall, both for their invaluable instruction and for inspiring my interest in economics.

I also wish to thank my graduate advisor Charles Plott and the rest of my committee: Jaksa Cvitanic, Robert Sherman and Peter Bossaerts for their help, advise, and many long hours of conversation spent discussing this thesis.

I thank: Kim Border, Leeat Yariv and Philip Hoffman for their help on my second year paper. David Grether, Robert Sherman Johnathan Katz, and Tae-Hwy Lee for teaching me econometrics and statistics. John Ledyard, Simon Wilkie, and Mathew Jackson for some of the most interesting economics course I have ever taken.

On a personal level I wish to thank Sandy Ma, without whom I might not have made it through graduate school, as well as Morgan Llewellyn, Mitchell Meeusen, Serkan Kucuksenel, Alex Brown, Sera Linardi, Dustin Beckett, Christoph Brunner, Min Jeong Kang, Ian Krajbich, Margaret McConnell, Alan Miller, Noah Myung, Julian Romero and Cheesmen Mullet I, for reasons that only he knows.

Abstract

Chapter One focuses on the movement of quote prices and the role of asymmetric information. Standard methods of estimating the impact of order flow shocks are made inappropriate by the existence of runs in trade initiation, which are theoretically impossible. We find runs that exist in trade initiation persist even after accounting for standard explanations. The chapter modifies the methodology of (Huang & Stoll, 1997) to use runs in trade initiation to account for the phenomena and estimates effects using ASX data.

Chapter Two introduces a new experimental environment in which the market is continuously shocked by new traders' incentives. The new environment joins two branches of theory. Classical economic theory has prices determined by the preferences of agents, but says little about the price formation process. The second theory is derived from finance in which prices are determined by the order flow coming to the market, but there is no connection between order flow and preferences.

We show that in such markets, two competing generalizations of the Walrasian equilibria exist corresponding to these competing literatures, each with an independent pull on market prices. Prices and efficiencies reveal a strong roll of expectations in price discovery and reject the idea that convergence is due to random or zero-intelligence trading strategies alone.

Chapter Three continues the analysis of Chapter Two by asking how the process of equilibration occurs in random arrival markets. We find that prices move proportional to the distance to the temporal equilibrium and show that this model's predictive power

is due to Marshallian features of the trading process as opposed the classical Walrasian adjustment model.

Chapter Four studies an RA environment in which some traders have asymmetric information regarding the distribution of latent incentives and arrival rates. We find that much of insiders' information is diffused as theory suggests and that much of the information is incorporated in outsiders' market actions. This diffusion of information is not a result of cumulative signed order flow, but is instead related to the observable rate of aggregate speculation. The ultimate implications of this phenomenon remain unknown.

Contents

Acknowledgements iii
Abstract iv
Contents vi
List of Figures ix
List of Tables xi
Introduction xii
Chapter 1 Inventory and Adverse Selection Effects in a Limit Order Market 1
1.1 Introduction 1
1.2 The Theory of the Bid-Ask Spread 3
1.2.1 Effective Spreads and Quoted Spreads 3
1.2.2 The Roll Model of the Effective Spread 4
1.2.3 Glosten/Milgrom and Ho/Stoll 5
1.2.4 The Stoll Decomposition of the Quoted Spread 6
1.3 The ASX and Limit Order Markets 8
1.3.1 Quality and Characteristics of ASX Data 8
1.3.2 Applicability of Inventory and Adverse Selection Models 9
1.4 Empirical Inconsistencies of the Roll and Stoll/Huang Stoll Models 10
1.4.1 Quoted and Effective Spreads in ASX Data 10
1.4.2 Explaining Differences Between Quoted and Effective Spreads 14
1.4.3 The Tendency for Reversals 16
1.5 Methodology 18
1.5.1 Predicting Changes in the Level and Slope of the Order Book 18
1.5.2 A Graphical Interpretation 19
1.5.3 Predicting Expected Order Flow 21
1.6 Results 22
1.6.1 The Level of the Bid-Ask Spread 22
1.6.2 The Slope of the Bid-ask Spread 29
1.7 Conclusions 33
Chapter 2 Principles of Continuous Price Determination in an Experimental Environment with Flows of Random Arrivals and Departures 34
2.1 Introduction 34

2.2 The Random Arrival and Departure Environment ... 36
2.2.1 Preference Inducement Methodology ... 36
2.2.2 Incentive Parameter Structure (Latent Incentives and Realized Incentives) ... 38
2.3 Market Institutions ... 42
2.4 Models and Theory ... 43
2.4.1 Temporal Equilibrium ... 43
2.4.2 Flow Competitive Equilibrium ... 44
2.4.3 Trader Behavior ... 49
2.5 Experimental Procedures and Design ... 52
2.5.1 Experimental Procedures ... 52
2.5.2 Experimental Design ... 53
2.6 Results ... 56
2.6.1 Overview ... 57
2.6.2 Price Levels ... 60
2.6.3 Efficiency ... 66
2.6.4 Bid and Ask Placement/Improvement: Evidence of Expectations Formation . 70
2.7 Conclusions ... 75
Chapter 3 The Dynamics of Price Adjustment in Experimental Random Arrival and Departure Environments ... 76
3.1 Introduction ... 76
3.2 Trading Environment and Known Results ... 79
3.2.1 Incentive Parameter Structure (Latent Incentives and Realized Incentives) ... 79
3.2.2 Types of Equilibrium ... 80
3.2.3 Known Results ... 82
3.3 Experiments Studied ... 83
3.4 Description of Data ... 86
3.4.1 Fat-Tails ... 88
3.4.2 Conditional Heteroskedasticity ... 88
3.4.3 Negative Autocorrelation ... 89
3.5 Results: Price Changes and the Dynamics of Price Movements ... 91
3.5.1 Limit Order Book Friction ... 91
3.5.2 Classical Models of Price Adjustment ... 97

3.5.3 The Marshallian Nature of RA Environments 116

3.6 Conclusions 125

Chapter 4 Experimental Random Arrival Markets with Competing Insiders 127

4.1 Introduction 127

4.2 Background and Trading Environment 128

4.3 Information Diffusion: Theory and Measurement 133

4.3.1 A Theory of Information Diffusion 134

4.3.2 Measuring Information Diffusion 136

4.4 Results 138

4.4.1 Informational Efficiency 138

4.4.2 Price Levels 139

4.4.3 Inventories 141

4.4.4 The Effects of Order Flow on Price Changes 147

4.5. Conclusions 152

Chapter 5 Bibliography 154

Chapter 6 Appendices 158

6.1 Appendices from Chapter1 158

6.1.1 Predicting the Size of Trade Initiation Runs 158

6.1.2 Forecasting Variance of Run Sizes 165

6.1.3 VAR Regressions of Bid-Ask Spread and Order Book 172

6.2 Appendices from Chapter 2 197

6.2.1 Instructions for Random Arrival Experiments 197

6.3 Appendices from Chapter 4 202

6.3.1 Help Information Given to All Traders 202

6.3.2 Hand Outs for Insiders and Uninformed Subjects 204

List of Figures

Figure 1.1: Quoted and Effective Spreads 12
Figure 1.2: Effective Spreads and Roll Estimator Using Transactions Data 13
Figure 1.3: Effective Spreads and CSS Estimator Using Transactions Data 13
Figure 1.4: Upward Price Adjustment in MBL 16
Figure 1.5: Estimated Hazard Rates for Reversals in IVC 17
Figure 1.6: Graphical Interpretation of Spread Component Estimation 20
Figure 1.7: 95% Confidence Intervals for Effect of Trade Size (at Ask Price) on Bid Price 25
Figure 1.8: 95% Confidence Intervals for Effect of Trade Size (at Ask Price) on Ask Price 26
Figure 1.9: 95% Confidence Intervals for Effect of Trade Size (at Bid Price) on Bid Price 26
Figure 1.10: 95% Confidence Intervals for Effect of Trade Size (at Bid Price) on Ask Price 26
Figure 1.11: 95% Confidence Intervals for Effect of Shocks (at Ask Price) on Bid Price ... 27
Figure 1.12: 95% Confidence Intervals for Effect of Shocks (at Ask Price) on Ask Price .. 27
Figure 1.13: 95% Confidence Intervals for Effect of Shocks (at Bid Price) on Ask Price ... 28
Figure 1.14: 95% Confidence Intervals for Effect of Shocks (at Bid Price) on Ask Price ... 28
Figure 2.1: Example Arrival of Private Orders (Incentives) for a Single Subject Before and After a Parameter Shift That Reduces the Flow of Orders to the Subject 40
Figure 2.2: Flow Competitive Supply and Demand Arrival Curves with 1000 Buyer and Seller Arrivals Per Hour 47
Figure 2.3: Flow Competitive Supply and Demand Arrival Curves with 500 Buyer and 1000 Seller Arrivals Per Hour 47
Figure 2.4: Flow Competitive Supply and Demand Arrival Curves with 1000 Buyer and Seller Arrivals per Hour and Shifted Latent Demand 48
Figure 2.5: Flow Competitive Supply and Demand Arrival Curves with 1000 Buyer and Seller Arrivals per Hour and Normally Distributed Latent Incentives 48
Figure 2.6: Flow Competetive Supply and Demand Parameters and Results for Market 070208 57
Figure 2.7: Flow Competetive Supply and Demand Parameters and Results for Market 070414 58
Figure 2.8: Flow Competetive Supply and Demand Parameters and Results for Market 070420 58
Figure 2.9: Flow Competetive Supply and Demand Parameters and Results for Market 070425 59
Figure 2.10: Flow Competetive Supply and Demand Parameters and Results for Market 070606 59
Figure 2.11: Distribution of Trade Prices Around FCE Price 61
Figure 2.12: Distribution of Trade Prices Around the TE Price 62
Figure 2.13: Distribution of TE Prices Around the FCE Price 62
Figure 2.14: Scatter Plot of Trade Price Deviations vs. TE Price Deviations from FCE 63
Figure 2.15: Distribution of Bids/Asks from FCE Before Parameter Shift 72

Figure 2.16: Distribution of Bids/Asks from FCE after Parameter Shift........................... 73
Figure 2.17: The Informational Entropy of Offer Price Distributions 74
Figure 3.1: Market-071208 86
Figure 3.2: ACF and PACF's of Price Changes and Squared Price Changes from
Experiments 070208 Through 071208.. 90
Figure 3.3: The Effect of Excess Demand for Varying Levels of dt.................................. 94
Figure 3.4: Limit Order Book Friction as a Function of Order Book Depths 96
Figure 3.5: Variables Used in Classical Models of Price Adjustment............................. 100
Figure 3.6: Typical Flow Competitive Supply and Demand Curves for Experiments 071205
& 071208.. 113
Figure 3.7: Waiting Times and Acceptance Probabilities for Incentives by Rent 123
Figure 3.8: Waiting Times until Incentives Transacted in Public Market 124
Figure 4.1: Supply and Demand Curves 131
Figure 4.2: Speculation Between low and High Equilibria 132
Figure 4.3: Rate of Speculation 135
Figure 4.4: All Experiments and Inventories 143
Figure 4.5: All Experiments and Inventories per Trader... 144
Figure 4.6: Scatter Plot of Price Changes Vs Size of Run Size 150

List of Tables

Table 1.1: Parameter Values under Competing Theories 6
Table 1.2: Quoted and Effective Spreads 12
Table 1.3: Estimated Parameters for ASX Stocks 15
Table 1.4: Summary of Effects: Bid, Ask and Spread Equations 25
Table 1.5: Summary of Effects: Quantities Offered at First Five Levels of Bid Order Book (QD1-QD5), Quantities Offered at First Five Levels of Ask Order Book (Q1-Q5) 32
Table 2.1: Theories of Trader Behavior 51
Table 2.2: Summary of Experiments 56
Table 2.3: FCE and TE in Forecasting Price Movement 65
Table 2.4: Efficiency 70
Table 3.1: Summary of Experiments 85
Table 3.2: Limit Order Book Friction as a Function of Order Book Depths 96
Table 3.3: Estimation of Equations 3.7a-f 103
Table 3.4: BIC for Classical Models 106
Table 3.5: Maximum Likelihood Estimation of Equations 3.8a-b 109
Table 3.6: The Nested Model 111
Table 3.7: Predicting Price Changes Based upon Inframarginal and Extramarginal Components of Excess Demand 115
Table 3.8: Cox Proportional Hazard Model Results 120
Table 4.1: Competing Theories of Information Diffusion 134
Table 4.2: Experimental Results 139
Table 4.3: Predicting Prices Based on Competing Equilibria 141
Table 4.4: Inventory Accumulation Rate of Uninformed Traders 146
Table 4.5: Inventory Accumulation Rate of Uniformed Traders 147
Table 4.6: Effect of Signed Run Size on Traded Prices 149
Table 4.7: Market And Limit Order Submission 151

Introduction

In continuous double auction markets, three fundamental forces are responsible for the movement of prices, immediate incentives, expectations, and information. This thesis explores each of those three forces. Many theories in the market microstructure literature have tended to focus on common value and/or informational aspects of the double auction market rather than its ability to find supply and demand equilibria. This is due to the continuous double auctions' application in financial markets, as well as the belief that supply and demand parameters can create an "induced common value," making the specification of supply and demand itself relatively unimportant.

Despite this theoretical focus in the literature, this thesis shows that commonly applied models of information diffusion fail to capture key aspects of price movement in the Australian Stock Market and in experimental continuous double auction markets. Moreover, the amount of variance in intraday price movements explained by asymmetric information is remarkably small.

Consequently, this thesis takes a different approach to the study of continuous double auctions. We apply an exploratory approach to a new kind of experimental environment. The environment of (Garman, 1976) and (Warren, 1975), in which limit order flow is modeled as a continuous Poisson process, is generalized to a full general equilibrium model in which supply and demand forming incentives to trade arrive to the market according to a Poisson process. The environment is termed "random arrivals" because it is as though new traders with their own preferences are randomly arriving to trade in the market. The new environment brings together two branches of theory.

Classical economics theory has prices determined by the preferences of agents assuming that the information revealed in market responses accurately reflects both the agent's preferences and information. This theory says very little about the details of the actual price formation process. The second theory is derived from finance in which prices are determined by the order flow coming to the market but the connection between this order flow and the underlying preferences is left abstract. Thus, this theory is not so much about equilibrium price discovery as it is the dynamics of the price making process. The role of the background incentives plays no role in this theory.

The new experimental environment lends itself to the study and integration of these two different bodies of theory. We show that in such markets, two competing generalizations of the Walrasian equilibria exist, each with an independent pull on market prices. One, which we call the flow competitive equilibrium, is similar to the classical law of supply and demand as found in economics. The other, which we call the temporal equilibrium, is similar to the price placing strategies and market microstructure found in finance.

By modeling supply and demand as a flow of short-lived incentives, we are able to demonstrate that multiple generalizations of the Walrasian equilibrium exist in continuous random arrival markets, and show differences in levels of market efficiency between those equilibria. Prices and efficiencies reveal a strong roll of expectations in price discovery. We reject the idea that convergence is due to random or zero-intelligence trading strategies alone.

The random arrival environment differs from traditional experimental environments in which incentives to trade are provided at the beginning of a number of (possibly overlapping) periods. The final chapter of the thesis also explores the role of asymmetric information in this environment.

The thesis asks fundamental questions such as, Do continuously evolving markets converge to supply and demand equilibria? How does this process happen? Which classical models best explain price dynamics? And how does information become incorporated into prices and efficiencies?

Key findings include:

- Multiple generalizations of the Walrasian equilibria exist in random arrival markets.
- Convergence to supply-demand equilibria is possible in continually evolving markets without the need for repetition.
- Prices in continuous double auctions are highly influenced by local or temporary imbalances in supply and demand. This is in contrast to predictions made by rational expectations with risk neutral agents.
- The ability of continuous double auctions to converge, as well as their tendency for prices to be influenced by local factors, is best explained by a kind of Marshallian dynamic. The speed with which traders enter the market, place bids and asks, and ultimately transact is a linear function of the amount of available profit on their immediate incentives at current market prices.

- On the other hand, expectations about future order flow do form and help to smooth prices and raise efficiency to levels that would be impossible with zero-intelligence agents.
- Measures of informational efficiency based on price convergence and measures based on efficiency levels can differ widely when applied to flow environments.
- The impact of asymmetric Information, when measured using the Ho/Stoll model, in both the Australian stock market and experimental random arrival markets with competing insiders is either small or non-existent. The proportion of variance in price changes explained by signed order flow is typically less than 10%.
- Experimental evidence from random arrival markets suggests that one possible explanation for this is that insiders hide their identities by placing both market and limit orders.
- If uninformed traders have well defined supply and demand functions, information held by insiders about the level of future prices is partially transmitted to uninformed traders through the rate of trade. This allows uninformed traders to speculate in the direction of insiders' information, but does not actually allow them to fully learn what insiders information is.

Chapter One: Inventory and Adverse Selection Effects in a Limit Order Market focuses on the role of asymmetric information in the Australian stock market. Theory predicts that, in markets where there is the possibility that some trades are motivated by asymmetric information, market makers will revise prices after each trade to account for the informational content of signed order flow, making the prior probability of a reversal in trade initiation greater than or equal to .5. This however, is not the case. Empirically, trade initiation in the Australian stock market is positively correlated, even after accounting for standard explanations of this phenomenon. Consequently, standard methods of estimating the effects of asymmetric information and inventory management on asset prices fail to yield interpretable results. In this chapter, we estimate the impact of adverse selection and dealer inventory effects by looking at runs in trade initiation. We conclude that inventory effects are significant even in non-dealer markets, although their effect is limited to the level of the bid-ask spread. Asymmetric information has a smaller impact on the level of the bid-ask spread, but does affects the depth of the market, and the slopes of the limit order books.

- Inventory effects are significant even in non-dealer markets.
- Asymmetric information has a smaller effect on prices than inventory effects, but does affect the curvature of the limit order book.

Chapter Two: Principles of Continuous Price Determination in an Experimental Environment with Flows of Random Arrivals and Departures studies an experimental continuous double auction environment with no asymmetric information. The period structure of classical experimental markets, which is known to play an important role in the equilibration process, is replaced by an environment in which incentives arrive randomly and continuously throughout. We show that in such markets, the focus on a single law of supply and demand is incomplete. There exist two competing generalizations of the Walrasian equilibria, each with an independent pull on market prices. The first we call the “Temporal Equilibrium,” which is based on the parameters that exist in the market at a moment in time and the second is the “Flow Competitive Equilibrium,” which reflects the underlying probabilistic structure of the parameters.

Human subjects are also able to achieve much higher levels of surplus extraction than would be possible from naïve trading strategies alone, though far less than 100% of the additional surplus due to expectations is realized. In particular, the amount of surplus due to expectations that traders are able to extract seems to be related to the strength of public signals regarding price changes. When shifts in the FCE price are due to changes in the distribution of latent incentives, subjects tend to extract more additional surplus due to expectations than when shifts are due to changes in the relative rates of arrivals.

The distance to the FCE and TE prices are the most important variables predicting both the location of new bids and asks as well as the probability of a bid or ask improvement. Large under pricings relative to either equilibrium concept are likely to result in a faster rate of market orders on the buy side, higher bid prices, and a greater chance of bid improvement. Similarly large over pricings relative to either equilibrium are likely to result in a faster rate of market orders on the sell side, lower ask prices, and a high chance of ask price improvement.

Additionally, market convergence also appears to be aided by the way in which subjects position new bids and asks over time. Over the course of an experiment, if the Flow Competitive Equilibrium is held constant, new bids and asks are influenced in the direction of the FCE price. The entire distribution of bids and asks, as measured by informational entropy, becomes more concentrated around the FCE price. Such changes in the distribution of bids and asks may be viewed as evidence of the formation of expectations.

- Trading in experimental RA markets generates high levels of efficiency relative to the maximum amount of surplus available. Realized surplus extraction is typically higher than the amount that could be obtained without speculation.
- Waiting times between trades are uncorrelated, and have a mean rate of transaction larger than the rate of transaction predicted by the FCE.
- The law of one price, in the sense of a constant price over time, does not emerge under conditions of a constant FCE price.
- Traded prices are distributed around both FCE and TE prices.
- When trade prices deviate from the FCE price, they tend to deviate in the direction of the TE price.
- Both the direction of temporal equilibrium prices and the direction of the FCE price influence price movement.
- Over time, human subjects place bids and asks closer to the FCE price. This process likely aids convergence.

Chapter Three: The Dynamics of Price Adjustment in Experimental Random Arrival and Departure Environments continues the analysis of Chapter Two by asking how the process of equilibration occurs. In this chapter, we test six competing classical models of price movement. We find that all models of price dynamics, when considered on their own, do equally well in explaining observed experimental data. However, when we nest all six models into a single equation, a clear winner emerges. Prices appear to move in direct proportion to the distance between the current price and the Temporal Equilibrium Price.

The distance to the temporal equilibrium appears to be the most important classical variable for several reasons. First, price dynamics are influenced only by the inframarginal portion of excess demand. Second, the speed with which individuals act on private incentives, and transact in the market is sensitive to the amount of profit available on each incentive at the current market prices. Incentives with higher rents at current offer prices were accepted faster in traders' private markets, traded quicker in the public market, and had higher probability of being acted on in general.

Such findings support the hypothesis that market convergence is in part aided by the "probabilistic Marshallian Path," that is, the idea that trades will form along the Marshallian path with greater probability than would occur by randomness alone.

The chapter also finds a significant role of price friction in price adjustments caused by the limit order book. The size and existence of the limit order book and the bid-ask spread also contribute to the occurrence of conditional heteroskedasticity in traded price time series.

- Price changes are relatively insensitive to excess demand between individual trades due to limit order book friction.
- The naïve OLS approach concludes that the best single predictor of per-trade price changes, in terms of the proportion of explained variation in dP, is the distance between the TE price and the current price. Distance to the FCE price

performs comparably well, followed by Excess Rent a distant third. (2) All of the non-fundamental models, including the classical Walrasian model individually explain less than 1% of the total variation in price changes.

- After adjusting for order book friction, auto correlation, and heteroskedasticity, there is little difference between models in terms of log likelihood.
- Significant levels of order book friction are observed for every single-variable model.
- A significant portion of heteroskedasticity is explainable by the size of the limit order books and the bid-ask spread.
- When all of the theoretically important variables are included in a single nested model, only the distance to the temporal equilibrium and potential gains from trade are statistically significant in predicting price adjustment. 2) Of the two significant variables, only the distance to the temporal equilibrium price is found to be significantly positive.
- Price dynamics are influenced only by inframarginal excess demand.
- The speed of transaction for units at the bid and ask price is influenced by the amount of rent available to the opposite side of the market at that price. The higher (lower) a bid (ask) is, the faster a transaction will occur at that price.
- Incentives with higher temporal equilibrium rents were 1) accepted faster in traders' private markets 2) had higher probability of being transacted in traders' private markets, and 3) transacted faster in the public market than lower rent incentives.

Chapter Four: Experimental Random Arrival Markets with Competing Insiders studies an RA environment in which some traders have asymmetric information regarding the distribution of latent incentives and arrival rates. Theory suggests that when more than one insider has identical information, insiders will price compete, eliminating all informational rent. We find instead, that insiders do not perfectly compete and that much of the information held by insiders is incorporated in non-informed traders' market actions. This diffusion of information is not a result of cumulative signed order flow, as predicted by theories of pure common value double auctions.

- Informational efficiency in random arrival market experiments with competing insiders is high, though typically below 100%. Approximately one third of information surplus accrued to insiders.
- Traded prices typically did not stabilize to the full information price. Hypothesis 2 is correct. Prices were slightly more likely to be found between the full information price and the FCE price.
- The inventory buildup of uninformed traders mirrors the inventory buildup of insiders.
- Uninformed traders use the observed rate of trade to speculate on the direction of the Full Information Price, but never learn either the identities of the insiders or the true location of the Full Information Price.

- The only significant determinant of inventory accumulation for uninformed subjects is the lagged total rate of speculation.
- The aggregate rate of insiders depends on location of the FCE price relative to the FIP. When the FCE is below the FIP, insider have a positive rate of inventory accumulation. When it is above the FIP, insiders have a negative, rate of inventory accumulation.
- Insiders are also affected by competition, accelerating their rate of inventory accumulation in direct response to past rates of accumulation.
- Informed subjects submitted both market and limit orders in the same proportion as uninformed traders.
- Asymmetric information in Random Arrival Markets is not transmitted through signed order flow. The direction of order flow however, does impact prices.

Chapter 1 Inventory and Adverse Selection Effects in a Limit Order Market

1.1 Introduction

This chapter looks at market microstructure data for a random sample of 10 Australian stocks from the S&P/ASX 200 from Jan 2006 to Mar 2006. We find that existing models of the bid-ask spread, when applied to microstructure data, fail to identify inventory holding cost and adverse selection components of the spreads, as well as misestimate effective spreads. We modify the basic methods of (Huang & Stoll, 1997) and apply our model to runs in trade initiation in order to decompose order processing, inventory, and adverse selection effects on the level and size of the bid-ask spread as well as determine how the depth and slope of the limit order books relate to these factors.

We find evidence that dealer inventory effects on the level of the spread exist even in limit order markets and that these effects are larger than those of adverse selection. Inventory effects do not appear to persist beyond the level of the spread, while adverse selection effects tend to affect the thickness of the limit order book, decreasing the depth of the market. Because bid and ask prices are revised separately in dealer markets, asymmetries in the effects of adverse selection can be seen between bid and ask prices. Quote prices respond more strongly to unexpected order flow shocks on the same side of the market, while changes in the inventory of limit order placers effects both quotes symmetrically.

This chapter attempts to connect two separate veins of financial literature: the literature related to the components of the bid-ask spread, and the newly emerging literature on limit order market microstructure. Its goal is two-fold, first to contribute to the bid-ask spread literature by showing how inventory, adverse selection and market making uncertainty affect not only the size and level of the spread, but also the depth and liquidity of the market. Second, to contribute to the limit order book microstructure literature by highlighting the importance of runs in trade initiations and the asymmetries in the behavior of the bid and ask order books.

Most of the empirical microstructure literature related to limit order markets has focused on predictable patterns in order flow and the interactions between volume, market depth, liquidity, and volatility (Bias, Hillion, & Spatt, 1995), (Danielson & Payne, 2001), (Ahn, Bae, & Chan, Limit Orders, Depth and Volatility: Evidence from the Stock Exchange of Hong Kong, 2001), (Bollerslev & Melvin, 1994). While these studies shed valuable light on the formation of limit order books and their impact on price movements and volatility, the literature has largely ignored issues such as the role of inventory holding costs, or to what extent components of the bid-ask spread influence the shape of the limit order book.

In part, inventory effects have been ignored in limit market order books because economists have questioned the relevancy of models of dealer inventory in non-dealer markets. Instead, theories of the spread specific to limit order markets have focused on the role of heterogeneity in traders' demand for immediacy, and the relative arrival rates of limit and market orders (Foucault, 1999), (Foucault, Kadan, & Kandel, 2003). Empirical works have tended to attribute order flow effects on price movement as stemming entirely from asymmetric information (Bias, Hillion, & Spatt, 1995), (Chan, 2005).

(Bias, Hillion, & Spatt, 1995) study the patterns of order flow in the Paris Bourse. They find that order flow is mainly concentrated at or near the best bid and best ask price, and that rates of limit order submission are negatively correlated with market thickness. Biais, Hillion, and Spatt also note that large trades on one side of the market are likely to cause changes in the level of the bid-ask spread, a result that they attribute to asymmetric information.

(Danielson & Payne, 2001) on the other hand, provide motivation for the existence of inventory effects and evidence of the importance of runs in trade initiation. They note that liquidity supply temporally clusters on one side of the market and removal of liquidity at the front of one side of the book implies increased probability of seeing fresh liquidity at the front of the other side of the book and lower chances of seeing subsidiary liquidity supply on that side of the book.

Section 1.2 of the chapter discusses the background theory of the bid-ask spread and the decomposition of its components. In Section 1.3, we discuss the characteristics of the Australian Stock Exchange (ASX) data and argue for the applicability of theories discussed in Section 1.2. In Section 1.4, we show how existing models of the effective and quoted spread fail to fit the data. We point out problems related to the tendency for trade initiation to remain on the same side of the market, and sketch the relationship between accumulated order flow and the probability of a reversal in trade initiation. Section 1.5 modifies the basic trade indicator model for spread decomposition into a VAR model of trade initiation runs. The results of this modified model are presented in Section 1.6. Section 1.7 concludes the chapter.

1.2 The Theory of the Bid-Ask Spread

1.2.1 Effective Spreads and Quoted Spreads

Two types of transaction costs exist in financial markets, quoted spreads and effective, or realized spreads. Quoted spreads are defined as the difference between the best asking price and the best bidding price. Today, quoted spreads can be observed in many different markets with reasonable amounts of accuracy. On the other hand, an effective spread is only realized when initiation of trade switches sides of the market and is defined as the amount that prices move due to the spread, at the times at which initiation changes.

While quoted spreads do represent real economic costs in terms of barriers to trade, the transactions costs that financial scholars are most interested in are the amounts that market makers have to be paid to compensate them for the cost and risks involved in making markets. The effective spread reflects the gross profit that market makers earn, while the remainder of the quoted spread is believed to exist in order to shield market makers from the risk of trading with better-informed traders (the information/adverse selection component) or the risk associated with large swings in inventory, which inevitably occur.

A simple example of the difference between quoted and effective spreads is the following. Suppose a market maker sets bid and ask prices of $2 and $3 respectively. During the first half of a day, ten people each sell one unit at the bid price. Afterward, the market maker sets new bid and ask prices at $1 and $2 respectively. Ten more people now buy one unit each at the ask price. Although the quoted spread was constant throughout the day, the $1 quoted spread was never realized since everyone bought and sold at the same price; hence, the average effective spread was zero.

1.2.2 The Roll Model of the Effective Spread

(Roll, 1984) provides a model for estimating the effective spread using the auto covariance of price changes, which is commonly applied in markets where the sequence of trade initiations is unknown. Roll assumes that in an efficient market, the probability of a trade occurring at the bid price is .5 and independent of past transactions. He argues that in such a market with only an order processing component of the spread, the movement of transaction prices between the bid and the ask creates negative first order auto covariance of transaction price changes. Using this relationship, Roll derives a simple estimator of the effective bid-ask spread:

$$\hat{S}_{Roll} = 2 * \sqrt{-\operatorname{cov}(\Delta P_t, \Delta P_{t-1})} \qquad (1.1)$$

(Choi, Salandro, & Shastri, 1988) generalized the Roll model by allowing for the possibility of serial covariance in the sequence of trade initiations—that is, the probability of the next trade being initiated at the bid (ask) price given that the last trade occurred at the bid (ask) price may differ from .5. Choi, Salandro, and Shastri reasoned that the conditional probability of a continuation might be larger than .5 because large market orders often initiate trades with more than one participant on the other side of the market. This causes single trades to be recorded as multiple sequential trades in ticker tape output. Choi, Salandro, and Shastri, derive a modified Roll estimator:

$$\hat{S}_{CSS} = \frac{\sqrt{-\operatorname{cov}(\Delta P_t, \Delta P_{t-1})}}{\pi} \qquad (1.2)$$

Where π is the probability of a trade reversal.

1.2.3 Glosten/Milgrom and Ho/Stoll

(Glosten & Milgrom, 1985) suggested a model in which some traders have inside information regarding the common value of an asset. In their model, the bid-ask spread reflects the amount that market makers must be compensated for constantly trading against informed traders. In Glosten and Milgrom, market makers adjust price levels to reflect information contained in order flow. If the last transaction occurred at the ask price, the market maker revises his or her expectation of the asset's value upward, moving bid and ask quotes up accordingly.

(Glosten, 1987), and (Glosten & Harris, 1988) consider the possibility that the bid-ask spread reflects a combination of an order processing cost, as discussed by Roll, and an adverse selection component, as discussed by Golsten and Milgrom. Glosten and Glosten and Harris claim that the Roll estimator reflects a "gross profit" condition—the profit made by market markers above and beyond the losses they receive from trading with informed traders. Because of the way information contained in order flow causes market makers to revise prices, Glosten and Glosten and Harris show that even though the adverse selection component inflates spreads, it does not contribute negative auto covariance. Therefore, they claim that the difference between observed quoted spreads and the effective spread estimated using Roll is due to adverse selection.

(Ho & Stoll, 1981) provide an alternative explanation for why quoted spreads might be larger than effective spreads. They present a model in which dealers have an ideal level of inventory holdings, which they try to maintain. After a dealer sale (purchase), the dealer will adjust prices upward (downward) to induce a dealer purchase (sale). Unlike adjustments due to information in Glosten and Milgrom, these adjustments do contribute negative serial covariance.

If quoted spreads reflect a combination of all three transactions costs: order processing, adverse selection and inventory holding costs, then the difference between observed and effective spreads reflects both adverse selection and inventory components of the spread.

1.2.4 The Stoll Decomposition of the Quoted Spread

(Stoll, 1989) shows that five parameters summarize the differences between the order processing, adverse selection, and inventory holding cost models of the bid-ask spread:

1. δ_r: the amount traded prices move when there is a reversal in trade initiation
2. δ_c: the amount traded prices move when trade continues on the same side of the market.
3. π: the probability of a change in trade initiation
4. Cov_t: the first order covariance of transaction price changes
5. Cov_q: the first order covariance of quote price changes, which Stoll claimed could be estimated from either the bid or ask time series[1]

The values for each of these parameters under the competing theories are listed in Table 1.1.

Table 1.1: Parameter Values under Competing Theories

Determination of Quoted Spread	δ_c	δ_r	π	Cov_t	Cov_q
Only Order Processing (Roll 1984)	0	S	0.5	$-0.25S^2$	0.0
Only Adverse Selection (Copeland, Galai 1983, Glosten, Milgrom 1985)	0.5S	0.5S	0.5	0.0	0.0
Only Inventory Holding Cost (Ho, Stoll 1981)	0.5S	0.5S	$1>\pi>0.5$	$-0.25S^2 < S^2(1-2\pi) - \pi^2(1-S) < 0.0$	$-0.25S^2 < S^2(1-2\pi) < 0.0$

Stoll's major contribution to the bid-ask spread literature was to notice that if the quoted spread was composed of a linear combination of an order processing cost, an adverse selection component and an inventory holding cost:

$$S = \alpha S_{orderprocessing} + \beta S_{AdverseSelection} + (1-\alpha-\beta) S_{InventoryHolding} \qquad (1.3)$$

then Equation (1.3) and Table 1.1 define a system of equations that can be solved for the relative proportions of each component of the quoted spread. Stoll estimates the

[1] Stoll (1989) used the covariance of bid prices. As Table 3 shows, the assumption that the covariances of bid and ask prices are the same is clearly wrong. In transactions data, the covariance of ask price changes is always greater than the covariance of bid price changes.

parameters from daily NASDAQ data and concludes that about 47% of the bid-ask spread is comprised of order processing costs, 43% adverse selection cost and 10% inventory holding costs.

(Huang & Stoll, 1997) generalized the methodology of (Stoll, 1989) using trade indicator models to estimate the components of the bid-ask spread for NYSE data. In their model, the "true" public information price of a stock evolves according to:

$$V_t = V_{t-1} + \alpha \frac{S}{2} \text{Unexpected change in inventory} + \text{ public information innovation}$$
$$= V_{t-1} + \alpha \frac{S}{2}\left(I_{t-1} - E[I_{t-1} \mid I_{t-2}]\right) + \varepsilon_t, \qquad (1.4)$$

Where I_t is an indicator function equal to 1, if a trade is designated as being buyer initiated, and -1 if seller initiated. This specification follows from the assumption that all trades are of unitary size. The expected change in inventory is simply:

$$E[I_{t-1} \mid I_{t-2}] = (1-2\pi)I_{t-2}, \quad \text{where } \pi \text{ is the probability of a reversal} \qquad (1.5)$$

The midpoint of the spread M_t, is assumed to be linearly related to the order flow imbalance experienced by market makers, which is simply the sum of the indicator functions. This comes from the model of (Ho & Stoll, 1981). In that model, the dealer's response to a change in inventory is given as the solution to a stochastic differential equation. Ho and Stoll do not solve this equation in the general case, or even show that there exists a solution to the general case. Instead, the conclusion that market makers will adjust prices linearly with changes in inventory is the result of several simplifying assumptions. Later, we will test this linearity assumption in evaluating the model.

$$M_t = V_t + \beta \sum_{i=1}^{t-1} I_i \qquad (1.6)$$

Combining Equations (1.4) and (1.6), Huang and Stoll derive the basic trade indicator model in which changes in the midpoint of the bid-ask spread are modeled as a function of lagged order flow, and expected order flow.

$$\Delta M_t = (\alpha + \beta)\frac{S}{2} I_{t-1} - \alpha \frac{S}{2}(1-2\pi)I_{t-2} + \varepsilon_t \qquad (1.7)$$

In this model, α reflects the percentage of the half spread attributed to adverse selection, and β reflects the percentage of the half spread due to inventory holding costs. (1-α-β) is interpreted as the order processing, or gross profit component of the half spread. In order to identify all of the parameters of this model, Huang and Stoll estimate the probability of a reversal separately and provide alternative specifications of the model depending on whether the quoted spread must also be estimated from the data.

Huang and Stoll note the potential for serious problems with their model. As in (Stoll, 1989), the probability of a reversal is a crucial parameter in the trade indicator model. Huang and Stoll observe the probability of a reversal to be significantly lower than .5 in NYSE data. As a result, when the model is first estimated, Huang and Stoll find the proportion of the half spread due to adverse selection to be negative—an impossible result.

Like (Choi, Salandro, & Shastri, 1988), Huang and Stoll assume that the problem stems from large market orders being incorrectly recorded as multiple consecutive trades. As a result, Huang and Stoll overcorrect for the problem of large trades by repeating their analysis combining all consecutive trades that occurred on the same side of the market less than 5 seconds apart. After doing this, they estimate that adverse selection accounts for about 9.6% of the spreads of NYSE stocks while the inventory component accounts for about 28.7%.

1.3 The ASX and Limit Order Markets

1.3.1 Quality and Characteristics of ASX Data

The ASX is a limit order market with a publicly visible order book. There is no institutionalized dealer or specialist, although there is a small collection of brokerage firms that routinely make up the inside of the order book. Trading on the exchange is conducted anonymously. According to the rules of the exchange, traders may place either market or limit orders. Although in practice, market orders are extremely rare, and almost all transactions occur due to overlapping limit orders with most overlapping orders hitting either the best ask or best bid depending on the side of the market. For our purposes, limit orders that transact immediately are effectively market orders, and will be referred to as such. The tendency for transacting limit order to hit the best bid (ask) rather than under (over) shoot, as well as the tendency for new limit orders to appear at the current best bid or ask price suggests that traders monitor orders closely.

The data used in this study come from a proprietary dataset compiled by Capital Markets Surveillance Services Pty Limited (CMSS), which consists of every bid, ask, amend, cancellation and trade on the Australian Stock Exchange (ASX). Unlike data from US dealer markets, our data is remarkably clean. Every bid, ask, cancellation and amend is recorded and labeled according to a unique bid or ask ID number. Each trade is accompanied by a bid and ask ID and a set of flags indicating whether the transaction was initiated by the buyer (transaction occurring at the ask price) or the seller (transaction occurring at the bid price) of the transaction and whether the trade occurred on market, off market, during the opening or closing auction, etc.

As a result, the potential problem noted by (Choi, Salandro, & Shastri, 1988), that large trades being broken up into multiple consecutive trades can result in biased estimates of the probability of a reversal, is non-existent in the data considered in this study. All consecutive trades that are initiated at the bid (ask) price and are associated with the same bid (ask) ID number are considered a part of the same trade.

1.3.2 Applicability of Inventory and Adverse Selection Models

A common objection to the methodology of this chapter is likely to be that the models of Roll, Glosten and Milgrom and Ho and Stoll, which we are applying to ASX data, are not specifically theories regarding limit order markets. While this is true, these theories are not specifically models of dealer or specialist markets either. Instead, all of the theories discussed above are models of stylized fictitious worlds in which a market makers (in this case, any trader who posts a limit price not for immediate execution) post fixed prices and individuals trade in unitary quantities with zero transaction risk.

While the market markers of theory are often referred to as “monopolist market makers,” their pricing does not depend on their monopoly power. (Glosten, 1987) argues that the presence of adverse selection exists in markets regardless of whether the market maker is a single monopolist or a group of competing market makers. Moreover, in Stoll's seminal paper on decomposing the effects of inventory and adverse selection, he uses data from the NASDAQ, which is a multiple dealer market. Even specialists are not monopolists. On average, NYSE specialists are involved in only 26% of all trades by volume (Hasbrouck & Sofianos, 1993).

The main substantive difference between limit order markets and dealer markets is not the monopoly power of the specialist but is the degree of market transparency and transaction risk. While some microstructure theories, such as (O'Hara & Oldfield, 1986), explicitly model the lack of transparency in dealer markets, the theories of Roll, Glosten and Milgrom, and Ho and Stoll are general enough that they do not account for order book transparency at all.

Whether market transparency is an important factor in determining bid-ask spreads is addressed in (Bortoli, Frino, Jarnecic, & Johnstone, 2006). Bortoli *et al* examine a natural experiment in which the Australian Futures Exchange made an institutional change toward greater order book transparency. The exchange increased the number of visible levels of quantity on the order book from the quantity available at the best bid and ask price to the quantities available up to three ticks away from the best offers in both directions. Measuring the average sizes of the bid-ask spread before and after the change, Bortoli *et al.* concluded that transaction risk does not affect quoted spreads, although it did reduce the depth of the market available at the best bid and ask.

1.4 Empirical Inconsistencies of the Roll and Stoll/Huang Stoll Models

1.4.1 Quoted and Effective Spreads in ASX Data

Using the time series of bid, asks, cancellations, amends and trades, we can reconstruct the evolution of the limit order book throughout the trading day. Since we also observe the sequence of trade initiations, we can compute the average quoted and effective spreads using Equations (1.8) and (1.9) below. We could alternatively calculate the average quoted spread weighting by the length of time that the size of the quoted spread persisted, or use inter-trade quotes as well. Weighting by time does not appear to affect our estimate of the average quoted spread in any significant way. The use of inter-trade quotes in the calculation as well tends to result in higher spread estimates since there is typically a time delay between when an order is lifted off the book and the time that quantity is replaced by another limit order. Using inter-trade quotes will produce positive bias in estimates of average quoted spreads related to the frequency with which limit order placers monitor a particular stock.

$$\bar{S}_{quoted} = \frac{1}{[\#of\ \ trades]} \sum P_t^A - P_t^B \tag{1.8}$$

$$\bar{S}_{effective} = \frac{1}{[\#of\ \ reversals]} \sum \left(P_t^A - P_{t-1}^B\right) Z_t + \left(P_{t-1}^A - P_t^B\right)\left(1 - Z_t\right), \tag{1.9}$$

$$where \quad Z_t = \begin{cases} 1 \text{ if trade reverses from the bid to the ask price} \\ 0 \text{ if trade reverses from the ask to the bid price} \end{cases}$$

For each stock, Table 1.2 lists the average quoted spread, the effective spread and two estimates of the effective spread obtained using the methods of (Roll, 1984) and (Choi, Salandro, & Shastri, 1988) . Table 1.2 also shows the price level of each stock at the beginning of the study and its average daily volume.

The actual and effective bid-ask spreads for all stocks tend to remain close to the minimum tick size of $0.01. Spreads exhibit some relationship to price levels, and possibly vary with trading volume as well; however, there is simply not enough data to make definite conclusions regarding either statement. The spread calculations in Table 1.2 also point out why expressing spreads in terms of returns may be problematic. If quoted and effective spreads remain close to the minimum tick size for all stocks, expressing them as fractions of a stock's share price artificially inflates the difference between the spreads of high and low priced stocks.

The effective bid-ask spread appears to be merely a fixed fraction of the observed quoted spread. Figures 1.1-1.3 plot the relationship between the effective spread, the quoted spread and the estimators listed in Table 1.2. Both the Roll and CSS models overestimate the true effective spread and, in terms of fit, perform almost as well as a fixed fraction of the quoted spread, about 2/3.

Table 1.2: Quoted and Effective Spreads

Stock	Average Quoted Spread	Effective Spread	Effective/ (Average Quoted Spread)	Roll Estimate of Effective Spread	Choi, Salandro, Shastri	Price (on 01/03/06)	Daily Vol
MBL	$0.0284	$0.0179	0.630	$0.0250	$0.0191	$68.00	145,679
NWS	$0.0156	$0.0086	0.551	$0.0098	$0.0073	$22.69	475,942
ANZ	$0.0152	$0.0080	0.526	$0.0101	$0.0077	$23.90	1,083,877
BBG	$0.0200	$0.0112	0.560	$0.0124	$0.0100	$14.50	321,130
AWC	$0.0117	$0.0065	0.556	$0.0072	$0.0057	$7.44	2,488,957
IVC	$0.0158	$0.0103	0.652	$0.0087	$0.0082	$4.11	53,389
QAN	$0.0106	$0.0075	0.708	$0.0069	$0.0058	$4.04	3,564,751
WPL	$0.0239	$0.0156	0.653	$0.0214	$0.0161	$39.25	854,692
ZFX	$0.0139	$0.0072	0.518	$0.0089	$0.0069	$7.00	3,126,523
GWT	$0.0142	$0.0082	0.577	$0.0078	$0.0066	$3.00	123,676

When Roll's estimator is computed using per-trade transactions data, Roll tends to underestimate quoted spreads while overestimating effective spreads. On average, Roll overestimates effective spreads by about 60% using transaction data. This improves when using the modification suggested by Choi, Salandro, and Shastri. Their estimator, however, still overestimates effective spreads by about 20%.

Figure 1.1: Quoted and Effective Spreads

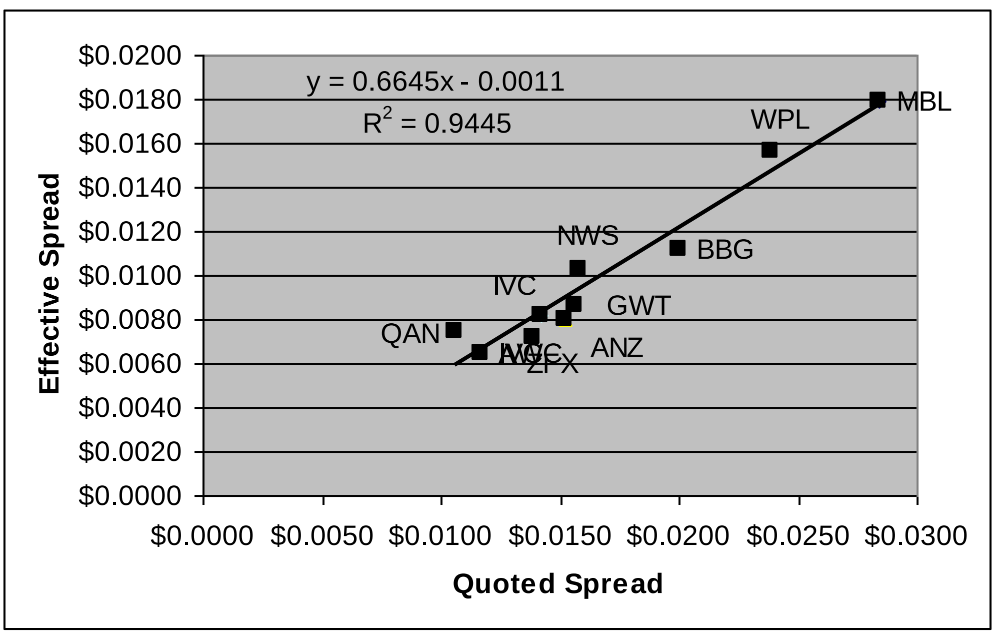


Figure 1.2: Effective Spreads and Roll Estimator Using Transactions Data

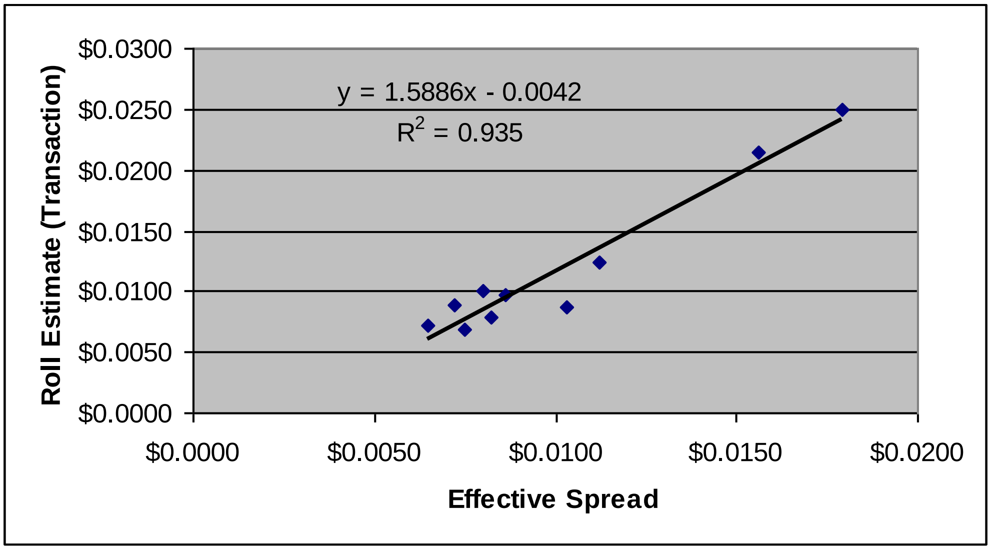
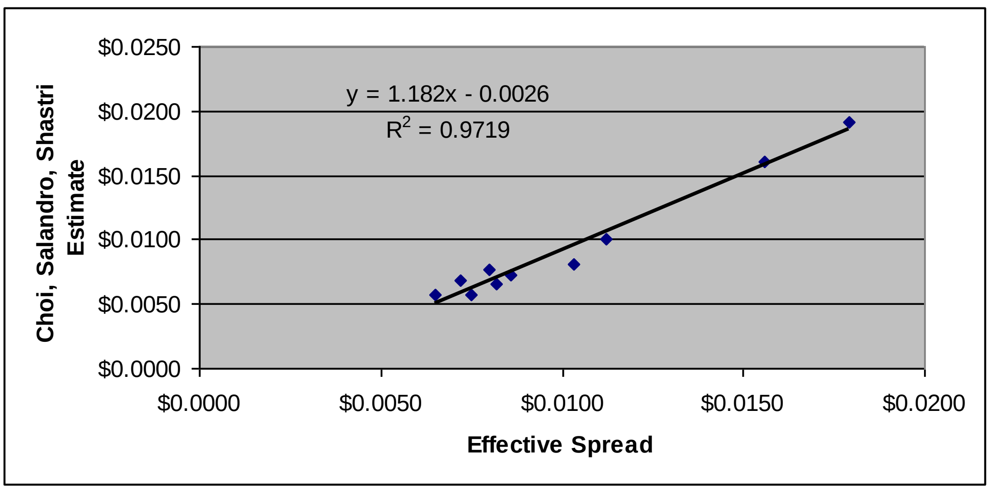


Figure 1.3: Effective Spreads and CSS Estimator Using Transactions Data



1.4.2 Explaining Differences Between Quoted and Effective Spreads

In order to explain the difference between quoted and effective spreads, we first try to adopt Stoll's (Stoll, 1989) methodology to estimate the size of the relative components of the quoted spread. For each stock, we use bid, ask, and transaction prices along with the observed sequence of trade initiations to estimate the parameters given in Table 1.1. We allow δ_c, δ_r and π to differ depending on whether the last trade was initiated at the bid (δ_{cb}, δ_{rb}, π_b) or ask price (δ_{ca}, δ_{ra}, π_a), and estimate the covariance of quote prices for bid and ask price time series separately.

We see major discrepancies between observed and theoretical values, particularly for π_b and π_a. Each of the theories discussed in (Stoll, 1989) held that the probability of a reversal is at least .5. The observed probability of a reversal for all stocks is closer to .4 and for some stocks, such as IVC, significantly less. The probability of a reversal being smaller than .5 reveals that no combination of inventory holding costs and adverse selection components, at least as previous researchers have envisioned them, can adequately explain the difference between quoted and effective spreads.

Table 1.3 also reveals that the covariance of quote prices depends on whether covariances are computed using the time series of bids or asks. In all ten stocks, the covariances of ask quotes are higher than the covariances of bid prices. Bid covariances are negative in all stocks, while ask covariances are positive in four stocks.

Table 1.3: Estimated Parameters for ASX Stocks

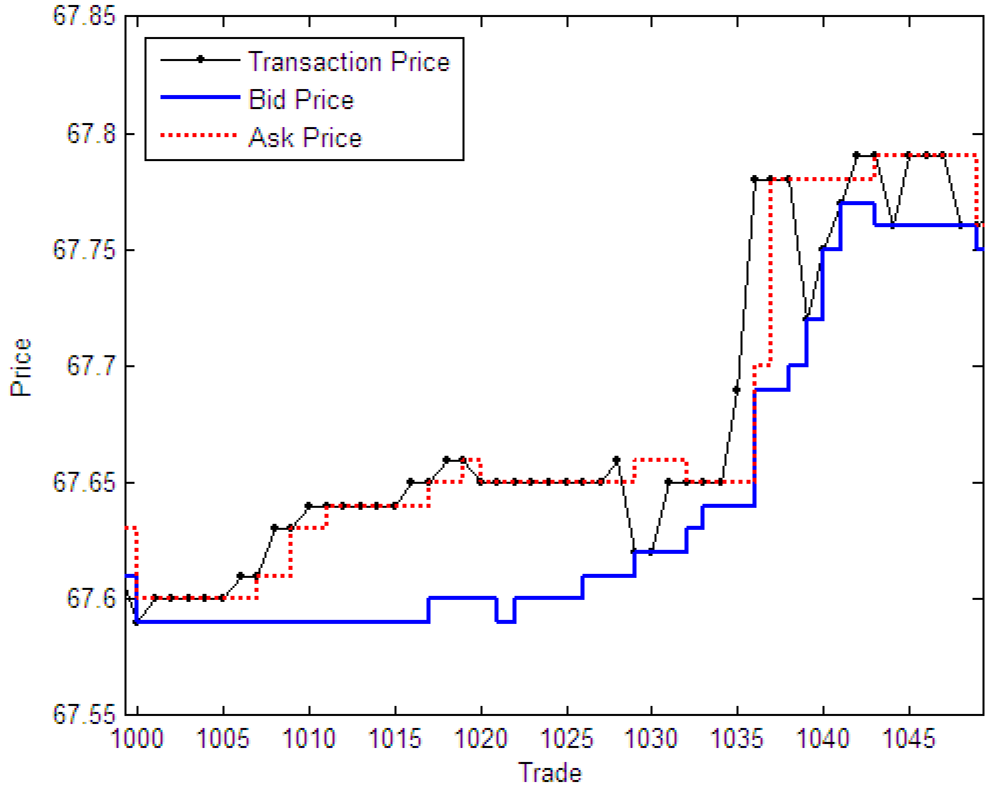
Stock	δ_{cb}	δ_{ca}	δ_{rb}	δ_{ra}	π_b	π_a	Cov_t	Cov_b	Cov_a
MBL	-$0.0078	$0.0064	$0.0152	-$0.0166	0.4681	0.3891	-1.56E-04	-1.22E-04	1.39E-04
NWS	-$0.0024	$0.0033	$0.008	-$0.0072	0.4046	0.5086	-2.42E-05	-7.39E-06	-2.91E-06
ANZ	-$0.0028	$0.0026	$0.0071	-$0.0075	0.4679	0.4001	-2.57E-05	-5.53E-06	-1.52E-06
BBG	-$0.0041	$0.0045	$0.0084	-$0.0086	0.3788	0.3873	-3.84E-05	-1.99E-05	6.75E-07
AWC	-$0.0016	$0.0015	$0.006	-$0.0059	0.4061	0.3934	-1.30E-05	-3.14E-06	2.75E-04
IVC	-$0.0014	$0.0019	$0.0093	-$0.0092	0.2625	0.3091	-1.90E-05	-1.25E-05	-8.61E-06
QAN	-$5.45E-04	$5.26E-04	$0.0076	-$0.0073	0.3129	0.4054	-1.20E-05	-4.97E-04	-1.41E-05
WPL	-$0.0062	$0.0057	$0.0131	-$0.0139	0.4725	0.4103	-1.14E-04	-0.0296	0.0013
ZFX	-$0.0021	$0.0019	$0.0067	-$0.0066	0.4387	0.3885	-1.97E-05	-2.28E-06	-7.24E-07
GWT	-$0.001	$0.0019	$0.0084	-$0.008	0.2648	0.4193	-1.50E-05	-2.71E-06	-1.66E-06

Ask covariances tend to be higher than bid covariances because of the way stock prices adjust. Contrary to theory, quote prices do not adjust simultaneously. One price often undergoes multiple sequential revisions in one direction before the other price adjusts once. Because stock prices tend to move upwards, ask price changes are more likely to accumulate positive auto covariance than bid prices.

Figure 1.4 illustrates a sequence of trades for MBL during a period of price adjustment. Stock prices adjust upward when a large number of trades initiated by buyers erode limit orders on the other side of the market. This erosion of ask orders pushes the ask quote upward, but more importantly, it causes ask prices to rise at a faster rate than bid prices, increasing the quoted spread.

Nearly all transactions during the illustrated period of price change occur at the ask price. To the perspective of potential sellers, as ask prices increase, bid prices becomes less attractive, and seller initiated transactions do not occur until after bid prices have begun to catch up with the ask price.

Figure 1.4: Upward Price Adjustment in MBL



1.4.3 The Tendency for Reversals

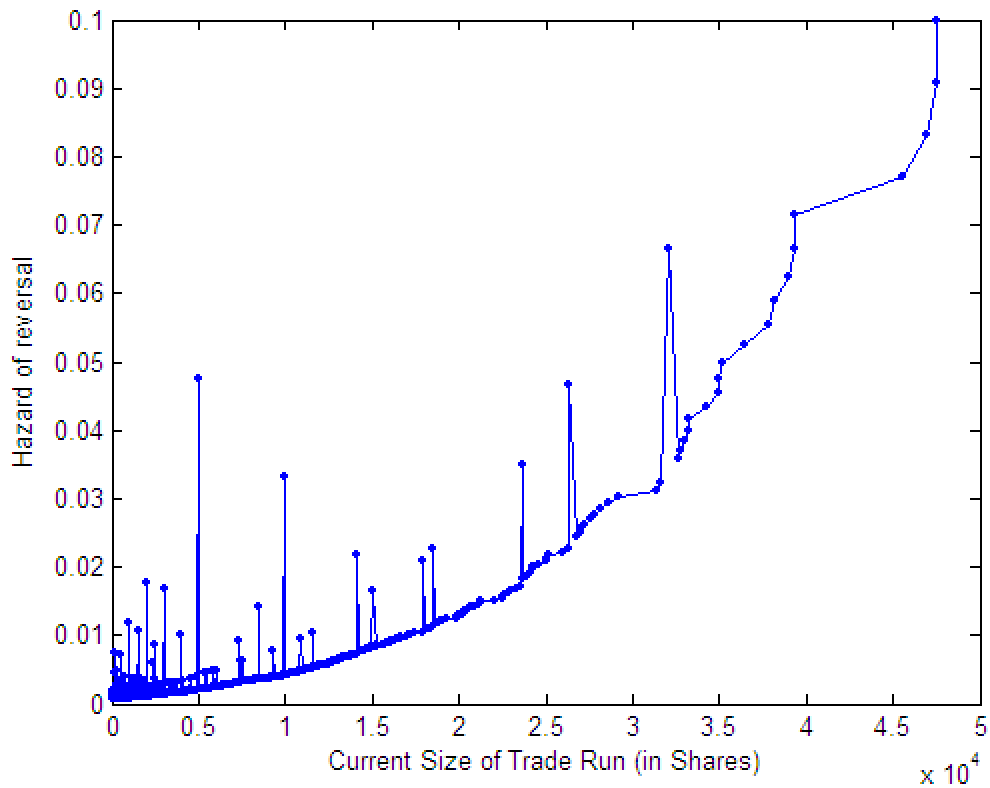
A natural question to ask given the low probability of a reversal is whether the probability of a reversal is increasing with the accumulated size of a continuation. It may be that markets have an "order flow threshold." That is, small trades, even groups of small trades on the same side of the market are unlikely to induce any revision of prices. Only if a large enough order arrives or if a run of small trades accumulates enough one-sided order flow, will markets undergo a price adjustment.

To answer this question, we consider the hazard rate of reversals. The hazard of a reversal at a quantity Q is defined to be the probability that a run experiences a reversal immediately after accumulating a size of Q shares conditional on having not experienced a reversal up to quantity Q. This can be estimated by dividing the empirical probability density function of run sizes by the one minus the empirical cumulative probability distribution.

Figure 1.5 below shows the typical shape of the relationship between the current size of a run and the instantaneous probability of a reversal. The estimated hazard rate functions of the stocks in this sample reveal that there is indeed a relationship between how long a continuation has already lasted and its instantaneous probability of ending. In general, the longer a run has continued, the more likely it is to end, although this relationship appears weak for a broad range of run sizes at the beginning of the distribution of run sizes.

Essentially, many small trades can accumulate on one side of the market before affecting the probability of a reversal in a meaningful way. As orders build up on one side, however, the probability of a reversal increases at a faster rate as orders in a run arrive.

Figure 1.5: Estimated Hazard Rates for Reversals in IVC



1.5 Methodology

1.5.1 Predicting Changes in the Level and Slope of the Order Book

Given the problems associated with the tendency for continuations in trade initiations, we propose a modification of the Huang and Stoll trade indicator model in which the probability of a reversal is set to one. Specifically, consider the sequence of trade initiations and quantities:

Trade Indicator	**1**	**1**	**1**	**-1**	**-1**	**1**	**-1**	**-1**
Quantity of Shares	100	300	200	500	100	300	200	100

Instead of looking at individual trades, we look at the alternating sequence of runs, measuring the size of the spread, the change in the level of the spread, and the depth of the market at and around the best ask and best bid on the limit order book between every run. The sequence of individual trades represented above then becomes the sequence of runs below:

Trade Indicator	**1**	**-1**	**1**	**-1**
Quantity of Shares	600	600	500	200

We then make similar assumptions regarding the effect of order flow on the true value of the stock and the relation between order imbalance and the "true" value of the stock. We assume that the change in the true price of a stock is a linear function of the size of the previous run, measured in shares, and the unexpected shock in order flow, also measured in shares. Similarly, we assume that the level of prices is a linear function of the true value and the size of the previous run. While Huang and Stoll focus on the mid point, we model changes in bid and ask prices separately in order to explore potential asymmetric effects on the spread.

We also relax the above mentioned linearity assumptions by testing possible non-linear forms, and include other covariates and autoregressive terms in our regressions.

$$V_t = V_{t-1} + \alpha\left(Q_{t-1} - E[Q_{t-1} \mid Q_{t-2}]\right) + \varepsilon_t \qquad (1.10)$$

We estimate the system of equations below where $\hat{Q}_{t-1}$ is an estimate of the size of the run at time t-1, based upon information available at time t-2, and the V's are vectors of autoregressive terms and the predicted variance of $\hat{Q}_t$. The vector of error terms of the system of equations is assumed contemporaneously cross-correlated while all other cross correlations are assumed zero.

Notice that in the equations below we have dropped the term S/2 from the original model. This is because we are no longer considering a fixed, point spread. By grouping all trades in a single run together, we are considering an "order flow" spread, which reflects how the interaction of market order flow and the arrival of new limit orders have changed the level of prices over the length of a trade run.

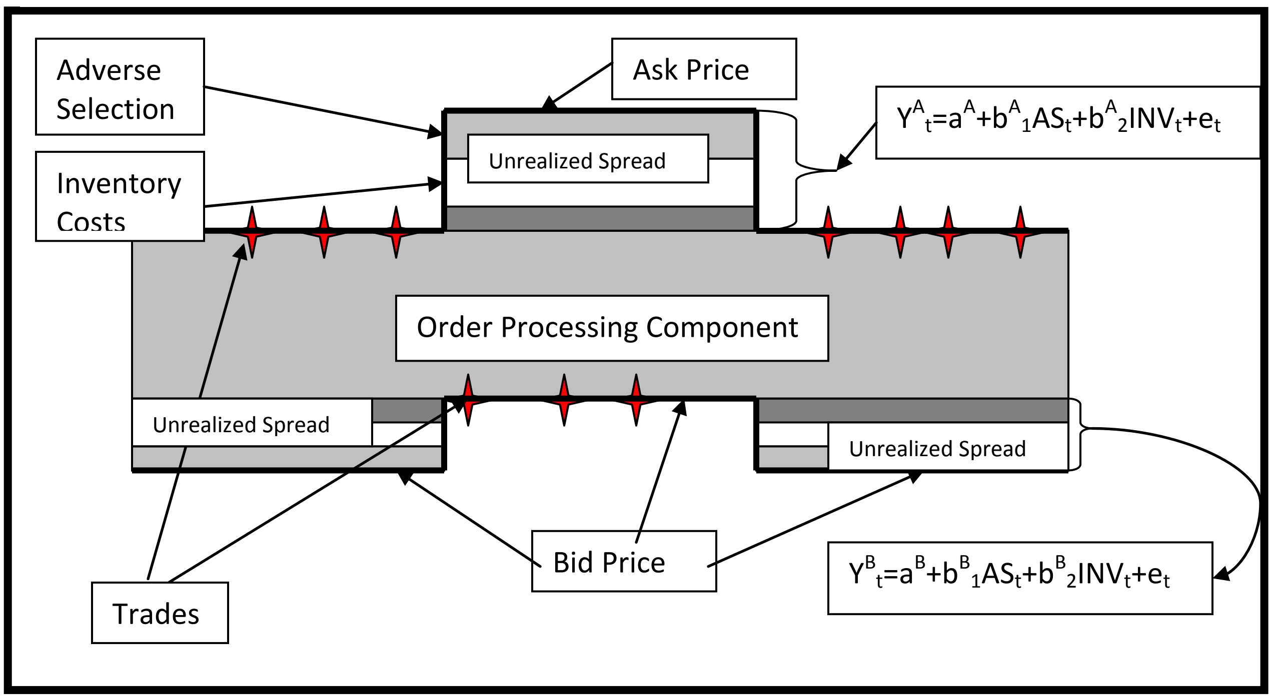
$$\begin{aligned}
\Delta P_t^A &= \delta^A + \beta^A Q_{t-1} + \alpha^A\left(Q_{t-1} - \hat{Q}_{t-1}\right) + \lambda^A V^A + \varepsilon_t^A \qquad (1.11)\\
\Delta P_t^B &= \delta^B + \beta^B Q_{t-1} + \alpha^B\left(Q_{t-1} - \hat{Q}_{t-1}\right) + \lambda^B V^B + \varepsilon_t^B\\
S_t &= \delta^S + \beta^S Q_{t-1} + \alpha^S\left(Q_{t-1} - \hat{Q}_{t-1}\right) + \lambda^S V^S + \varepsilon_t^S\\
Q1 &= \delta^{Q1} + \beta^{Q1} Q_{t-1} + \alpha^{Q1}\left(Q_{t-1} - \hat{Q}_{t-1}\right) + \lambda^{Q1} V^{Q1} + \varepsilon_t^{Q1}\\
&\vdots\\
Q5 &= \delta^{Q5} + \beta^{Q5} Q_{t-1} + \alpha^{Q5}\left(Q_{t-1} - \hat{Q}_{t-1}\right) + \lambda^{B} V^{Q5} + \varepsilon_t^{Q5}\\
QD1 &= \delta^{QD1} + \beta^{QD1} Q_{t-1} + \alpha^{QD1}\left(Q_{t-1} - \hat{Q}_{t-1}\right) + \lambda^{QD1} V^{QD1} + \varepsilon_t^{QD1}\\
&\vdots\\
QD5 &= \delta^{QD5} + \beta^{QD5} Q_{t-1} + \alpha^{QD5}\left(Q_{t-1} - \hat{Q}_{t-1}\right) + \lambda^{QD5} V^{QD5} + \varepsilon_t^{QD5}
\end{aligned}$$

1.5.2 A Graphical Interpretation

On average, bid and ask prices tend to go up after a trade run at the ask price, and tend to go down after a run at the bid price. Because the probability of a reversal at the end of a run is one, the amount by which the ask price increases after a run at the ask price reflects the unrealized part of the flow spread after an ask run. Similarly, the amount that the bid price decreases after a run at the bid price is the unrealized part of the flow spread after a bid run.

After each run, we measure the amount that the price on the same side of the market as the previous trade changed. This is denoted either $Y_t = Y_t^A$ if the previous trade was at the ask price or $Y_t = Y_t^B$ if the previous run was at the bid price in Figure 1.6 below. Between each run, just prior to the start of the new run, we also measure the size of the previous run, denoted as INV in Figure 1.6, and the amount that its size differed from its predicted size, denoted AS below. Measurements of the components of the spread are obtained by regressing Y on run size and the size of the shock to determine the relative importance of the two components of the unrealized spread.

Figure 1.6: Graphical Interpretation of Spread Component Estimation



1.5.3 Predicting Expected Order Flow

In order to accurately measure the effects of adverse selection on stock prices, we must predict the size of future order flows given the information available just prior to the time of a reversal. The size of consecutive runs can be correlated for many different reasons. According to the theory we are interested in evaluating, order flows at consecutive runs are correlated because of market making activities that adjust the level of bid and ask prices in order to induce changes in inventory.

We also know from other micro market studies of order flow and liquidity that the volume of trade obeys certain predictable time patterns. For example, order flow tends to start high following the opening auction, fall off towards the middle of the day and picks back up near the close of the market. Volume is also known to differ depending on the day of the week or month. Volume tends to be different on Mondays and Fridays as well as the first and last days of the month. The relation between volume and time of day found in this study is similar to typical U-shaped pattern of volume found in (Ahn & Cheung, 1999) and (Bias, Hillion, & Spatt, 1995).

When forecasting future order flow, it is important to distinguish between the amount of correlation in run sizes caused by market making activities, and the amount that is merely because consecutive runs are jointly influenced by the same latent variables affecting the level of volume in general. If Ho and Stoll are correct that market makers affect future order flow in response to past inventory changes, we should expect past order flow to forecast future order flow even in the presence of variables controlling for time. Moreover, we should expect the predictive power of past inventory to be robust to the presence of time variables.

For every stock, both time and lagged run sizes were significant in predicting future run sizes. While we do not interpret any of the estimated relationships as being causal, the influence of lagged run size variables on predictions of future run size were consistent with theory. Large trades at the bid price tended to predict large future volume at the ask price and visa versa.

We also explore the possibility that future inventory depends on past runs deeper than the first lag. We find past lags significant in predicting run size, although the length of lagged dependence appears to extend only to the second lag.

Presumably, market makers are aware of predictable time patterns of volume, and anticipate them in their pricing. Thus, we use both sources of correlation to predict the unexpected shocks to market makers' inventory.

We will also forecast the expected variance of future run sizes as a linear function of the same variables used in forecasting the mean of future run size. We place no restrictions on the parameters of the variance equation to assure that the variances are positive, but verify after estimation that each observation in the sample has positive expected variance. Generally, the number of negative variance predictions is small, less than 1% of the sample size. These observations are then set to zero.

$$Q_t = \alpha + \beta_1 Q_{t-1} + \beta_2 Q_{t-2} + \text{lagged price changes} + \text{time of day variables} + \text{day of week/month dummies} + \varepsilon_t \quad (1.12)$$

$$\varepsilon_t^2 = \alpha' + \beta_1' Q_{t-1} + \beta_2' Q_{t-2} + \text{lagged price changes} + \text{time of day variables} + \text{day of week/month dummies} + \eta_t \quad (1.13)$$

1.6 Results

1.6.1 The Level of the Bid-Ask Spread

The analysis of our data indicate that the size and level of the bid-ask spread is determined by three components: an order processing cost, which constitutes the majority of the quoted spread, an inventory cost, and adverse selection cost. The effect of inventory and adverse selection costs, as predicted by theory, are similar, both tending to move prices in the direction of the previous trade run.

Table 1.4 summarizes the effects of inventory and adverse selection on the movement of bid prices, ask prices and the size of the quoted spread. We summarize the effect of the variables of interest in Table 1.4 by presenting the mean of the effects averaged across stocks, as well as the standard deviation of estimates and the minimum and maximum estimated values. We also provide counts of how many times out of ten, the estimated effect of the variable was positive and negative, regardless of the significance of that result.

As a simple non-parametric test of the inventory and adverse selection hypotheses, we compare the number of times an effect was estimated to be positive (negative) to the probability of obtaining the same or greater number of positives (negatives) under the null hypothesis that positive and negative results are equally likely.

Theory predicts that large volume and unexpected volume at the ask price will cause prices to go up and that large volume and unexpected volume at the bid price will cause prices to go down. Ten out of ten times the effect of quantity traded at the bid price was found to have a negative effect on the bid price, and ten out of ten times the effect of quantity traded at the ask price was found to have a positive effect on the ask price. The probability of this happening by chance alone is only about 1%. We also find that quantity at the ask (bid) price had a positive (negative) effect on bid (ask) prices nine (nine) out of ten times as well, an event with about 2% probability.

Less significant results are obtained for the effects of adverse selection. Adverse selection also appears to have asymmetric effects on bid and ask prices with bid prices responding more strongly to run size shocks at both the bid and ask prices. This asymmetry may be related to the tendency for the bid order book to exhibit a higher degree of curvature than the ask order book as the slope and curvature of the book is essentially a measure of prices' sensitivity to volume. Unexpected shocks at the ask price had a positive effect on bid and ask prices in 7 stocks each, while unexpected shocks at the bid price had a negative effect on bid and ask prices in 8 and 10 stocks respectively.

In the cases in which estimated effects of shocks were in the opposite direction as that predicted by theory, they also tended to be insignificant. For example, the smallest effect of unexpected shocks at the ask price on the level of the ask price was a whole order of magnitude smaller than the mean effect across stocks. The one exception to this was the effect of shocks at the ask price on the level of the bid price, for which one stock had a significantly negative estimate.

Overall, a trade run at the ask price one standard deviation larger than the mean can expect to increase bid and ask prices by slightly more than half a cent. On the other hand, a run at the bid price one standard deviation larger than the mean can expect to lower bid and ask prices by slightly less than half a cent. Because of a large amount of skewness in the distribution of run sizes, most run sizes lie somewhere between +/-1 standard deviation from the mean, but runs +5, +6, even +13 standard deviations or more away from the mean are not uncommon, certainly much more probable than they would be under a normal distribution.

The effect of observing an unexpected shock in run size one standard deviation large than the mean at the ask price tends to raise the ask price by about .3 cents, while having little impact on the immediate movement of the bid price. Similarly, a one standard deviation shock at the bid price will decrease the bid price by about .3 cents as well, and will have an effect about half that size on the ask price.

The asymmetry between how bid and ask prices respond to information contained in order flow is particularly theoretically important. Typically, theory has assumed that the bid-ask spread is either constant, or that when bid and ask prices are revised, that they are revised simultaneously. In a dealer market, where bid and ask prices are periodically announced by a specialist such as on the NYSE, this is not a bad assumption. However, in a limit order market, prices changes occur one at a time when orders at the front of the book are lifted, cancelled or improved.

In theory, inventory effects are caused by dealers' desire to rebalance inventory— induce dealer sales after dealer purchases, and visa versa—hence, in a market where prices are revised separately, the inventory effect is an effect that betters prices on the side of the market *opposite* the previous trade run[2]. Conversely,

[2] Prices cannot always be improved on the opposite side of the market as the previous trade run because of the minimum tick size. If the bid-ask spread is currently at the minimum tick size, the only way to improve prices at the opposite side of the market is to move both bid and ask prices together. This may explain why inventory has a significant effect on both sides of the market regardless of the side of the previous run—

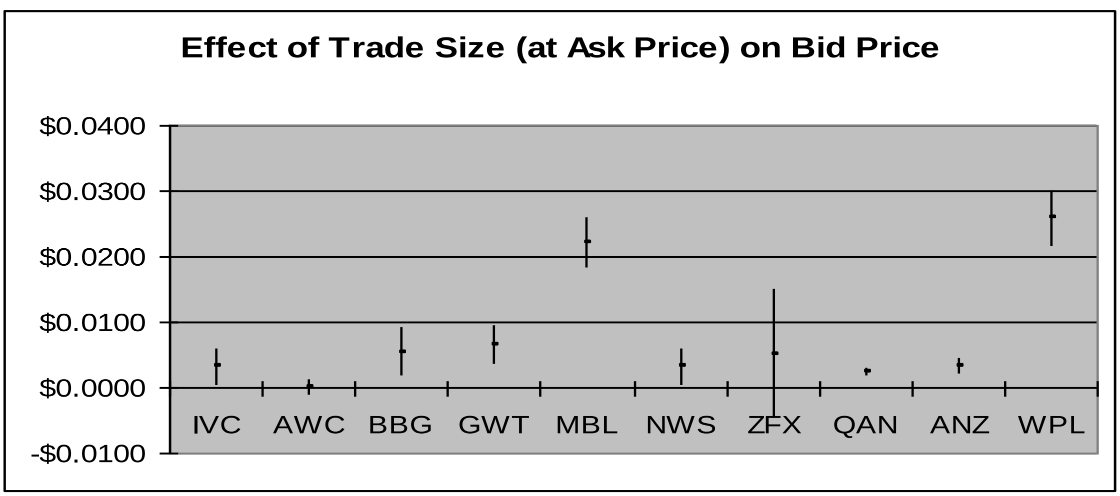
information effects are caused by dealers adjusting prices in ways that reduce order flow from informed traders, hence when prices adjust separately, adverse selection is primarily an effect that worsens prices on the *same* side of the market as the previous run. In light of how the two effects of information and inventory are likely to affect bid and ask prices differently, it is not surprising that we find inventory effects have a larger impact on prices on the opposite side of the market than do adverse selection effects.

Table 1.4: Summary of Effects: Bid, Ask and Spread Equations

	Last Run at Ask Price	Quantity Traded at Ask Price in Previous Run	Quantity Traded at Bid Price in Previous Run	(Quantity Traded at Ask Price in Previous Run)^2	(Quantity Traded at Bid Price in Previous Run)^2	Unexpected Shock at Ask Price	Unexpected Shock at Bid Price	Variance of Run Size	Constant
dbestbid									
average	0.0050	0.0077	-0.0041	-0.0004	0.0003	-0.0002	-0.0031	0.0000	-0.0015
std dev	0.0027	0.0088	0.0031	0.0005	0.0004	0.0064	0.0026	0.0004	0.0024
min	0.0016	-0.0001	-0.0120	-0.0016	-0.0003	-0.0145	-0.0084	-0.0004	-0.0047
max	0.0102	0.0258	-0.0004	0.0000	0.0009	0.0069	-0.0003	0.0008	0.0038
# Positive	10	9	0	2	8	7	0	4	2
#Negative	0	1	10	8	2	3	10	6	8
dbestask									
average	0.0040	0.0051	-0.0045	-0.0006	0.0002	0.0026	-0.0017	0.0001	-0.0014
std dev	0.0026	0.0053	0.0049	0.0007	0.0006	0.0039	0.0034	0.0006	0.0020
min	0.0011	0.0005	-0.0156	-0.0024	-0.0013	-0.0026	-0.0075	-0.0005	-0.0055
max	0.0094	0.0156	0.0000	0.0002	0.0009	0.0110	0.0049	0.0016	0.0025
# Positive	10	10	1	2	8	7	2	4	1
#Negative	0	0	9	8	2	3	8	6	9
spread									
average	-0.0012	-0.0017	0.0002	-0.0001	-0.0002	0.0019	0.0008	0.0001	0.0263
std dev	0.0011	0.0025	0.0012	0.0002	0.0002	0.0025	0.0018	0.0002	0.0760
min	-0.0040	-0.0077	-0.0017	-0.0006	-0.0008	-0.0004	-0.0012	-0.0001	0.0006
max	0.0002	0.0005	0.0021	0.0001	0.0001	0.0077	0.0044	0.0007	0.2426
# Positive	1	3	7	3	1	8	6	8	10
#Negative	9	7	3	7	9	2	4	2	0

x	P(X>=x|p=.5)
1	0.999
2	0.990
3	0.947
4	0.831
5	0.627
6	0.382
7	0.178
8	0.062
9	0.019
10	0.010

Figure 1.7: 95% Confidence Intervals for Effect of Trade Size (at Ask Price) on Bid Price



because when the spread is small same-side price movement is a prerequisite for adjusting opposite-side prices in ways that correct inventory imbalance.

Figure 1.8: 95% Confidence Intervals for Effect of Trade Size (at Ask Price) on Ask Price

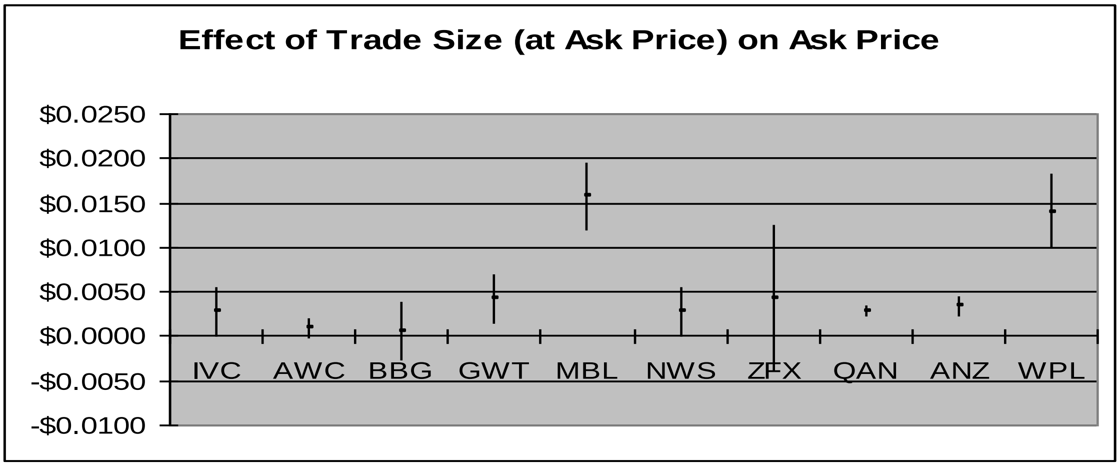


Figure 1.9: 95% Confidence Intervals for Effect of Trade Size (at Bid Price) on Bid Price

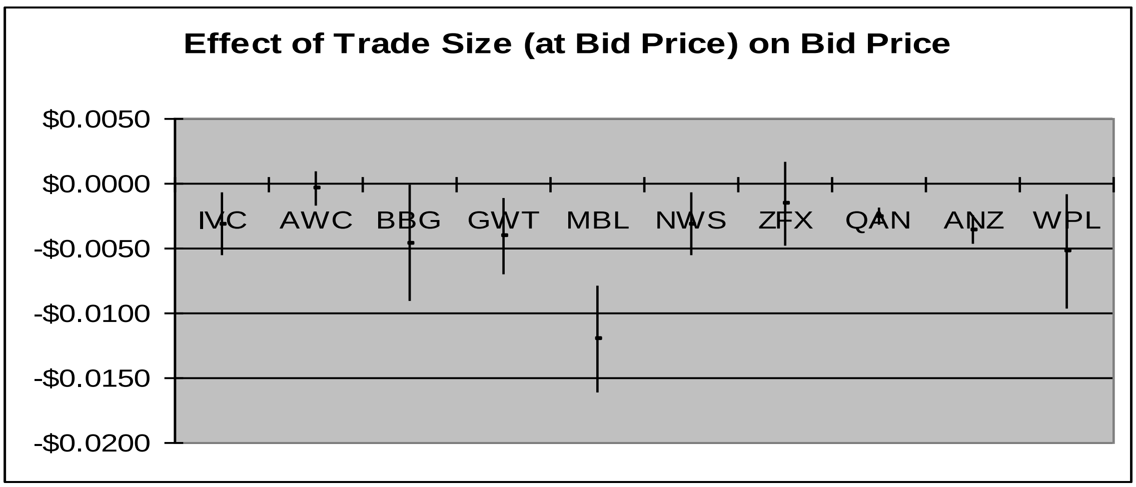


Figure 1.10: 95% Confidence Intervals for Effect of Trade Size (at Bid Price) on Ask Price

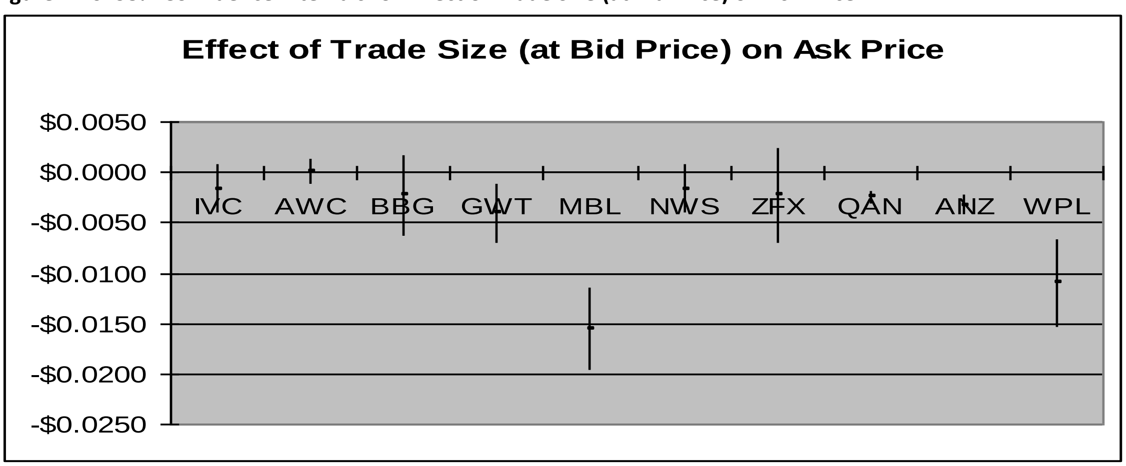


Figure 1.11: 95% Confidence Intervals for Effect of Shocks (at Ask Price) on Bid Price

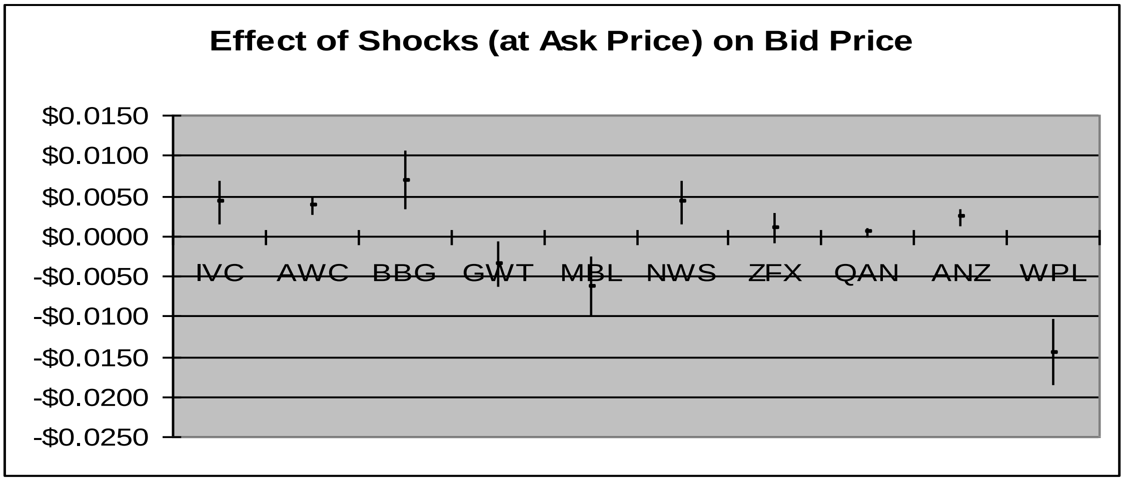


Figure 1.12: 95% Confidence Intervals for Effect of Shocks (at Ask Price) on Ask Price

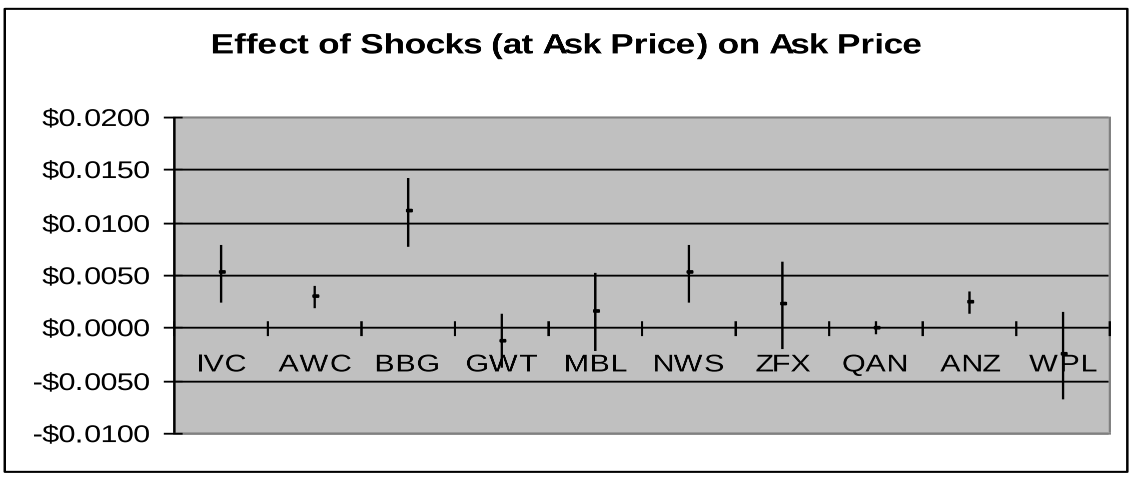


Figure 1.13: 95% Confidence Intervals for Effect of Shocks (at Bid Price) on Ask Price

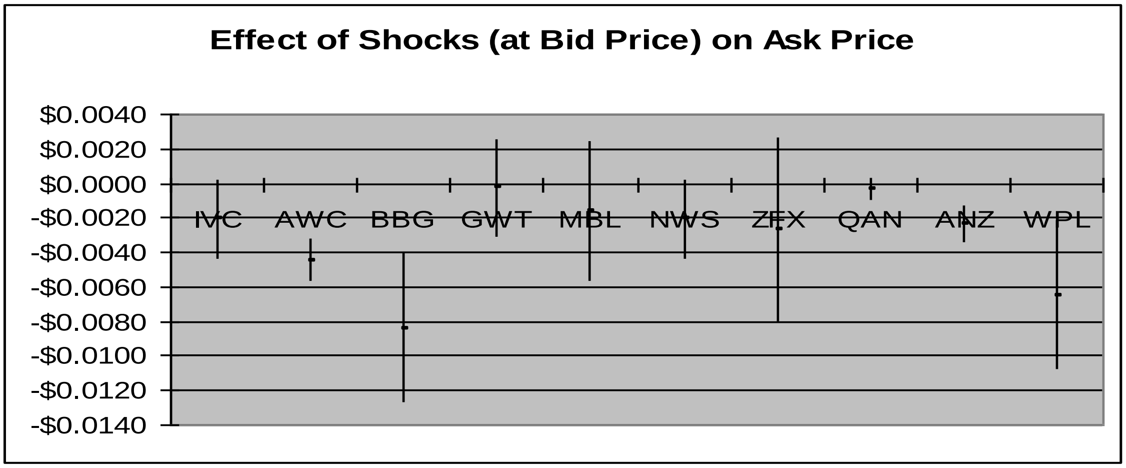
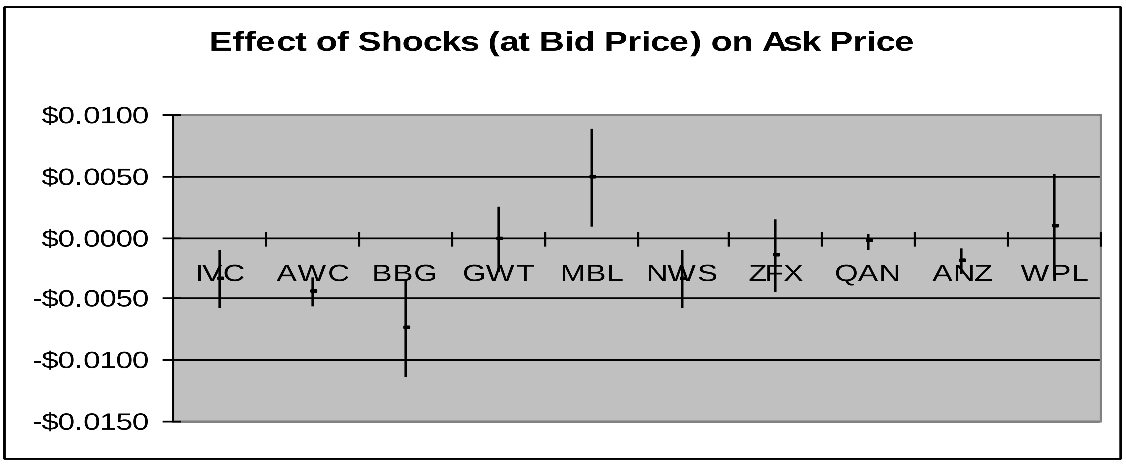


Figure 1.14: 95% Confidence Intervals for Effect of Shocks (at Bid Price) on Ask Price



In addition to looking at the effects of trade size, we also explore possible non-linear relationships between trade size and price movement, by including non-linear transforms of trade size in the price change equations. Table 1.4 includes a summary of the estimated effect of trade size squared as an example. While these effects are significant in some individual stocks, their effects are not consistently in the same direction across stocks.

This suggests that runs of extreme sizes are fundamentally different from runs of moderate size, but their effect on price movement may depend on other unobservable factors. For example, the effect of a large trade may depend on whether it follows an announcement of public information.

A notable feature of exceptionally large runs is that, in some stocks, they do not generate any price movement at all, while in others, prices tend to move in the direction of the trade, as one would intuitively expect. Eliminating large trade runs, those thirteen standard deviations or more from the mean run size, as outliers often does change the estimated effect of squared run size, but the estimated effect of run size and unexpected shocks in run size appear robust to their elimination. Inventory and adverse selection shocks are also robust to the presence of squared run size, log(run size) and lagged price change variables.

As expected, the error vectors of the change in ask price and change in bid price equations are highly correlated with correlations ranging from .85 to .95. This means that bid and ask prices tend to be moved in the same direction by the arrival of public information shocks, which are independent of order flow. At the same time, the errors of the price change equations are not as nearly as highly correlated with the errors of the spread equation, suggesting that the arrival of public information affects the size and level of the bid-ask spread differently.

The spread equation is the only place that we tend to see a significant effect of run size variance. The idea that large variance in run sizes tend to increase the bid-ask spread seems vaguely consistent with past research which has found positive relationships between the size of the bid-ask spread and price volatility (Ahn, Bae, & Chan, 2001) and (Bollerslev & Melvin, 1994).

1.6.2 The Slope of the Bid-ask Spread

The effect of inventory costs, adverse selection and uncertainty are more complicated with respect to the depth and slopes of the order book. The slopes of the order book are significantly affected by inventory and adverse selection, but not in the ways one would intuitively expect from theory. In theory, large trades and/or large unexpected shocks in dealer inventory at the ask price should increase prices. Since the depth and slope of a book reflect the price of quantity, one might intuitively expect a decrease in depth and an increase in the slope of the ask order book following a large trade at the ask price.

In practice, the order books appear to be more affected by demand for liquidity than anything else. High transaction volumes at both bid and ask prices appear to increase the depth and liquidity of the market. Essentially, market makers observe trade sizes and respond to increased demand for liquidity by placing additional limit orders at or around the best bid and ask. Large volumes of trading at either price tend to result in deeper markets and decreasing slopes of the order book. This result is consistent with (Danielson & Payne, 2001), which finds significant feedback effects between the rates at which market and limit orders enter the market for the Reuters D2000-2 USD/DEM foreign exchange market.

Table 1.5 below reports the same statistics as Table 1.4 for the depth of the market at the ask price (Q1) and the next four levels closest to the best ask (Q2-Q5), as well as the depth at the best bid (QD1) and the four closest levels of the bid offer curve (QD2-QD5). In all of the regressions Q1-Q5 and QD1-QD5 have been standardized by their mean and standard deviation, so that all effects are interpreted relative to the average quantity available at that price level. This is to make results comparable across stocks with different levels of liquidity.

The amount that a trade size increases the level of the quantity available at the first five price ticks on both sides of the market varies widely between stock, and between price levels. This variation between levels may be related to gaps in the order book, prices at which little if any quantity is offered. In general, a trade on either side of the market one standard deviation larger than the mean will result in an improvement in depth at a given price level between 1% and 10 % of the standard deviation in the level of quantity available at that price.

In contrast, large unexpected shocks in volume at either price tend to slow limit order flow relative to market order flow and increase order book slopes. The expected variance of run sizes appears to have minimal, if any, significant relationship to either the bid or ask order book. Just as unexpected shocks had an asymmetric effect on the level of spreads, they also appear to have an asymmetric effect on liquidity. Shocks at the bid price tend to affect both the bid and ask order books out to the fifth price level, while the effect of ask shocks on the bid order book appears to lose significance after only one level.

Unexpected shocks in order flow at the bid price appear to have a more significant impact on market liquidity than shocks at the ask price. A shock at the bid price one standard deviation above the mean will result in a decrease in quantity offered at every level of both order books between 5% and 20% of the standard deviation of quantity at those levels. Comparatively, ask price shocks will decrease the quantity offered at the best bid price by about 3% of a standard deviation with little or no effect on other price levels of the bid order book. The effect of ask price shocks on the ask order book does appear to extend further than the depth at the best ask price, however. A one standard deviation shock will result in about a 5% to 30% standard deviation reduction in the quantity offered at each level of the ask book.

Table 1.5: Summary of Effects: Quantities Offered at First Five Levels of Bid Order Book (QD1-QD5), Quantities Offered at First Five Levels of Ask Order Book (Q1-Q5)

	Last Run at Ask Price	Quantity Traded at Ask Price in Previous Run	Quantity Traded at Bid Price in Previous Run	(Quantity Traded at Ask Price in Previous Run)^2	(Quantity Traded at Bid Price in Previous Run)^2	Unexpected Shock at Ask Price	Unexpected Shock at Bid Price	Variance of Run Size	Constant
QD1									
average	-0.2249	-0.0434	0.2487	0.0079	0.0045	-0.0262	-0.2884	-0.0054	0.1624
std dev	0.0632	0.0653	0.0596	0.0203	0.0204	0.0364	0.0777	0.0230	0.0445
min	-0.2931	-0.1218	0.1317	-0.0275	-0.0274	-0.1093	-0.4414	-0.0537	0.0764
max	-0.0801	0.0942	0.3444	0.0452	0.0468	0.0265	-0.1728	0.0269	0.2389
# Positive	0	3	10	6	5	1	0	4	10
#Negative	10	7	0	4	5	9	10	6	0
QD2									
average	-0.0090	0.0334	0.1051	-0.0069	-0.0156	-0.0337	-0.0832	0.0138	0.0317
std dev	0.0547	0.0775	0.0894	0.0249	0.0294	0.0730	0.0839	0.0312	0.0387
min	-0.0595	-0.0449	-0.0126	-0.0671	-0.0883	-0.1721	-0.1853	-0.0180	-0.0310
max	0.0922	0.2035	0.2212	0.0182	0.0163	0.0493	0.1001	0.0929	0.0938
# Positive	3	5	7	5	3	3	1	7	8
#Negative	7	5	3	5	7	7	9	3	2
QD3									
average	0.0148	0.0154	0.1126	-0.0007	-0.0035	-0.0302	-0.1304	0.0046	0.0264
std dev	0.1015	0.1327	0.2033	0.0133	0.0138	0.0918	0.2074	0.0150	0.0374
min	-0.1239	-0.1833	-0.0502	-0.0291	-0.0284	-0.1937	-0.5104	-0.0127	-0.0212
max	0.1770	0.2005	0.4892	0.0171	0.0126	0.0970	0.0668	0.0278	0.0940
# Positive	4	6	7	6	5	3	3	5	6
#Negative	6	4	3	4	5	7	7	5	4
QD4									
average	-0.0182	0.0086	0.0264	0.0004	0.0012	-0.0066	-0.0403	-0.0002	0.0168
std dev	0.0566	0.0625	0.0945	0.0122	0.0143	0.0712	0.0862	0.0136	0.0206
min	-0.1214	-0.0573	-0.1555	-0.0141	-0.0161	-0.1367	-0.1817	-0.0248	-0.0233
max	0.0581	0.1557	0.1601	0.0267	0.0240	0.0940	0.1044	0.0171	0.0461
# Positive	4	4	7	5	6	5	3	6	9
#Negative	6	6	3	5	4	5	7	4	1
QD5									
average	-0.0346	0.0860	-0.0320	0.0166	0.0191	-0.0953	0.0051	-0.0195	0.0274
std dev	0.0618	0.0883	0.1164	0.0236	0.0236	0.1258	0.1373	0.0258	0.0235
min	-0.1467	-0.0208	-0.2434	-0.0091	-0.0079	-0.3143	-0.1465	-0.0520	-0.0179
max	0.0278	0.2295	0.0658	0.0500	0.0535	0.0528	0.2546	0.0095	0.0577
# Positive	3	9	6	6	6	1	2	4	9
#Negative	7	1	4	4	4	9	8	6	1
Q1									
average	0.0829	0.0766	0.1544	-0.0100	-0.0076	-0.0519	-0.1140	0.0077	0.0041
std dev	0.0584	0.1100	0.1568	0.0258	0.0252	0.0808	0.0868	0.0265	0.0458
min	0.0186	-0.1183	-0.0586	-0.0389	-0.0306	-0.1604	-0.2708	-0.0475	-0.0788
max	0.1617	0.2305	0.4058	0.0454	0.0473	0.0548	-0.0039	0.0385	0.0543
# Positive	10	8	9	2	3	3	0	8	6
#Negative	0	2	1	8	7	7	10	2	4
Q2									
average	-0.0367	0.1442	0.0493	-0.0057	-0.0010	-0.1434	-0.0628	0.0039	0.0619
std dev	0.0655	0.1319	0.0736	0.0285	0.0288	0.1613	0.0430	0.0290	0.0437
min	-0.1475	-0.0722	-0.0570	-0.0549	-0.0503	-0.4165	-0.1342	-0.0407	0.0137
max	0.0263	0.3584	0.1406	0.0384	0.0420	0.1075	-0.0161	0.0544	0.1363
# Positive	4	9	8	4	5	1	0	6	10
#Negative	6	1	2	6	5	9	10	4	0
Q3									
average	0.0443	0.0506	0.2210	-0.0003	-0.0023	-0.0586	-0.1828	-0.0023	0.0379
std dev	0.1510	0.1820	0.3048	0.0148	0.0156	0.1608	0.2440	0.0119	0.0765
min	-0.1255	-0.1918	-0.0664	-0.0321	-0.0282	-0.3650	-0.6290	-0.0281	-0.0318
max	0.2943	0.3772	0.7794	0.0266	0.0296	0.1584	0.0196	0.0188	0.1834
# Positive	6	7	9	4	6	3	1	2	6
#Negative	4	3	1	6	4	7	9	8	4
Q4									
average	-0.0099	0.0295	0.0557	0.0013	0.0020	-0.0450	-0.0392	-0.0018	0.0196
std dev	0.0377	0.0621	0.1075	0.0050	0.0077	0.0668	0.0936	0.0069	0.0189
min	-0.0780	-0.0291	-0.1869	-0.0052	-0.0087	-0.2068	-0.1876	-0.0095	-0.0028
max	0.0556	0.1757	0.1839	0.0089	0.0099	0.0193	0.1572	0.0071	0.0617
# Positive	4	6	8	7	5	2	2	4	9
#Negative	6	4	2	3	5	8	8	6	1
Q5									
average	0.0348	0.0494	0.0930	0.0024	-0.0022	-0.0806	-0.0891	0.0007	3025.4187
std dev	0.0634	0.0551	0.1599	0.0143	0.0152	0.0517	0.1298	0.0148	9567.1483
min	-0.0531	-0.0099	-0.0797	-0.0260	-0.0343	-0.1890	-0.4039	-0.0148	-0.0095
max	0.1869	0.1735	0.4588	0.0196	0.0144	-0.0014	0.0653	0.0350	30254.0000
# Positive	8	8	7	8	6	0	3	3	8
#Negative	2	2	3	2	4	10	7	7	2

x	P(X>=x|p=.5)
1	0.999
2	0.990
3	0.947
4	0.831
5	0.627
6	0.382
7	0.178
8	0.062
9	0.019
10	0.010

1.7 Conclusions

Previous models of the bid-ask spread that have focused on the probability of a reversal as a key parameter in decomposing spreads cannot reliably be used in markets where there is a large tendency for trade continuations. Even simple modes such as the Roll model, which do not distinguish between inventory and adverse selection components cannot be accurately used to measure the difference between effective and quoted spreads in markets with large runs in trade initiation.

By considering runs as fundamental elements of limit order markets, a clearer picture of the role of inventory management and asymmetric information emerges. Dealer inventory effects on spreads are not unique to dealer or specialist markets. They exist even in limit order markets and their effect on the level of bid-ask spreads is larger than that of adverse selection.

Decomposition of the spread also allows one to focus on changes in the order book specifically due to adverse selection. Asymmetric information plays a smaller role in the level of the spread, but has wide-ranging effects on the depth and shape of the order book. Unexpected shocks in the size of run volume decrease the flow of limit orders relative to market orders resulting in lower liquidity and steeper order books. Inventory effects, on the other hand, have little if any influence on market liquidity.

The relationship between unexpected shocks in order flow and the order book is also asymmetric. Shocks due to asymmetric information have a greater impact on the level and slope of the order book on the same side of the market as the shock. Shocks arriving at the bid price also have a greater influence on liquidity than do shocks at the ask price.

These differences between inventory and adverse selection effects raise new questions regarding the causality of the observed relationship between order book steepness and price volatility, and are likely to be a fruitful area of further research.

Chapter 2 Principles of Continuous Price Determination in an Experimental Environment with Flows of Random Arrivals and Departures

2.1 Introduction

The period structure of experimental double auction markets, developed by (Chamberlin, 1948) and refined by (Smith V. , 1962), is known to play an important role in Market equilibration. But is the repetition of trading days a necessity for convergence, and in what ways do continuous markets differ from period-style experiments? In this chapter, we show that 1) periods are not necessary for price equilibration, 2) multiple generalizations of the Walrasian equilibrium exist in a continuous environment, with each equilibria exerting a unique "pull" on prices, and 3) that expectations play an important role in the convergence of continuous markets.

In the experimental markets we study, incentives arrive at random times, are short lived, and come from stochastic processes which change over time. The first generalization of the Walrasian equilibrium is simply the price that would clear the incentives currently in the market irrespective of expected future arrivals. We call this the ***Temporal Equilibrium (TE)***. The second generalization of the Walrasian equilibrium to the continuous random arrival environment we call the ***Flow Competitive Equilibrium (FCE)***, which represents the price at which the expected flow of buy and sell incentives are equalized.

The environment we consider is similar to the environment examined theoretically in the finance literature by (Garman, 1976) and (Amihud & Mendelson, 1980). The works of Garman and Amihud and Mendelson, however, neglect the existence of Temporal Equilibrium prices, focusing exclusively on Flow Competitive Equilibrium and the effects of dealer inventories on prices fluctuations around the FCE price. Both works essentially take it for granted that expectations about the flow of supply and demand drive convergence. Other researchers, outside the realm of finance, such as (Gode & Sunder, 1993) and (Brewer, Jiang, & Plott, 2003) show that price convergence to the Walrasian equilibrium can be attained with “zero-intelligence” traders, raising the possibility that market convergence may have little if anything to do with human expectations.

While the temporal equilibrium can be thought of as a naïve or myopic equilibrium model that could be attained by purely random behavior alone, the FCE is a model of expectations, which would require real human intelligence. We discover that, with human subjects, both equilibria exert independent influences on prices.

Continuous markets with random arrivals and departures have the unique feature that speculation is necessary for obtaining high levels of efficiency. Speculation becomes a necessity because appropriate trading partners do not always exist in the market at the same point in time. Buyers and sellers may arrive in random “lumps,” causing temporary imbalances in supply and demand. To obtain levels close to one hundred percent efficiency, markets makers or speculators must be willing to smooth temporary supply imbalances over time. The markets we study here do demonstrate levels of efficiency significantly larger than those attainable from random or naïve trading strategies alone. Despite a lack of direct coordination of market timing, nearly all of the potential gains from trade are realized.

The chapter is divided into seven sections. The first section is this introduction. The second outlines the random arrival and departure environment that we explore. The third section is a discussion of the market institutions. The fourth section develops principles that are natural generalizations of classical principles and illustrates how they apply to the complex random arrival and departure environment. The fifth section details the experimental procedures and design and outlines the experiments conducted. The sixth section contains the results, and the final section contains concluding remarks.

2.2 The Random Arrival and Departure Environment

2.2.1 Preference Inducement Methodology

Classical experimental market environments, as introduced by (Chamberlin, 1948) and (Smith V. , 1962), consist of a set of redemption values, costs, and a period structure. Before the start of a period, buyers receive redemption values from the experimenters and sellers receive costs. Buyers make money in an experiment by buying units in a public market, in which all subjects can participate, and reselling them to the experimenters at the redemption values the experimenters privately quote each buyer. Similarly, sellers buy units from the experimenters, at costs the experimenters quote, and resell them to other subjects for a profit. Redemption values and costs can be modeled as limit prices and used as parameters in a model of competitive supply and demand equilibrium. When a period opens, subjects choose what incentives they will act on and form trades in the public market. Each period typically lasts for a fixed length of time. After each period, subjects receive additional redemption values and costs while old redemption values and costs do not carry forward to new periods. Additionally, units that exist in one period typically are not carried over to the next period; inventories and cash typically refresh each period.

Thus, in the classical environment, each period is like a day in which commodities are traded and completely depreciate over night. The day starts with a stock of costs and redemption values. During the day, the gains from exchange explicit in the stock are exhausted. All actions are coordinated by the beginning and ending of the period.

By contrast, the random arrival environment has no period structure. The market opens for a fixed length of time, typically about two hours. Incentives arrive in the form of private orders to buy from the experimenters (i.e., costs for potential sellers) or private orders to sell to the experimenters (i.e. redemption values for potential buyers) in a market accessible only by the agent for whom the orders are intended (i.e., the agent's private market)[3]. Buyers have an opportunity to buy in the public market from other agents and resell for a profit in their private market by accepting an order to sell to the experimenters found there. Similarly, sellers accept private orders to buy from

---

[3] This method of implementing the random arrival of incentives is made possible by the Caltech Marketscape technology that will be explained in greater detail in later sections.

the experimenters found in their private markets and resell units to other agents in the public market.

Private orders to buy and sell appear in agents' private markets at random arrival times and each order expires after a short period if not acted on. This expiration feature is important because it forces the individual to decide whether or not to act on an order during a specific interval of time. The incentives can appear at any time for any subject and last as long as the experimenters choose. Thus, at any instant, a subject can have many orders for different amounts that appeared in the subject's private order book at different times and have different expiration times.

2.2.2 Incentive Parameter Structure (Latent Incentives and Realized Incentives)

The basic parameters will be called "*latent buyer incentives*" and "*latent seller incentives*." The latent buyer incentives consist of a probability density function g_b(x), where x is a price. Latent seller incentives consist of a probability density function g_s(y), where y is a price. For individual agents, draws are made from the distribution of buyer values and the distribution of seller costs according to two independent Poisson processes with intensities λ_s and λ_b respectively.

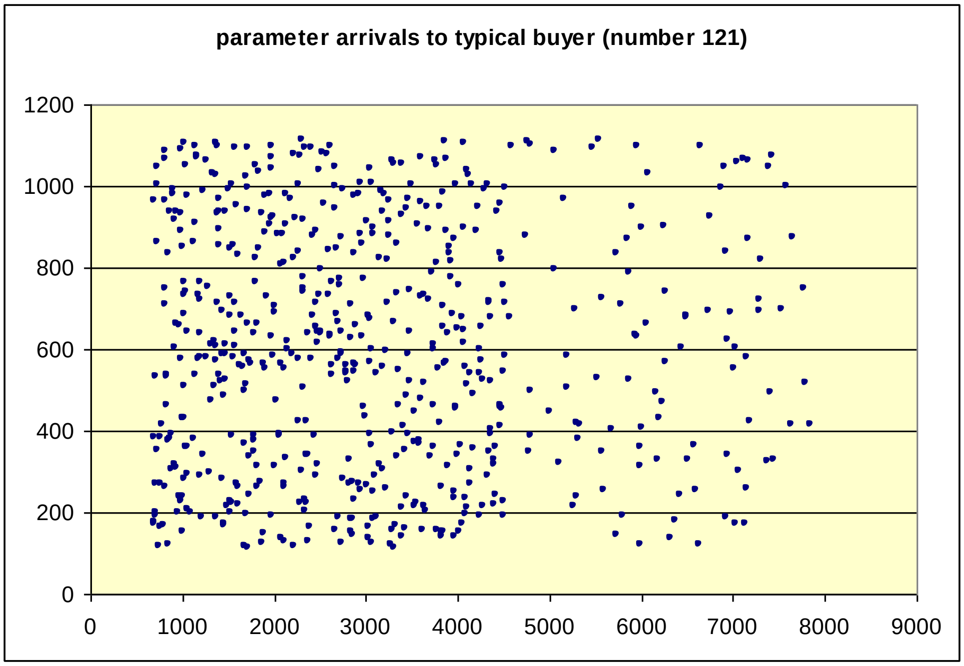
Realized incentives, as opposed to latent incentives, are the draws that are actually sent to buyers' and sellers' private order books and serve as "redemption values" and "costs." In designing experiments, λ_s is the arrival rate of private orders for each of the n_s sellers, and λ_b is the arrival rate of private orders for each of the n_b

buyers. An order sent to a private order book has a life δ_b and δ_s for buyers and sellers respectively. In these experiments, δ_b and δ_s are fixed lengths of time (6 minutes), but this need not be true in general. The environment could easily be modified to include random expiration according to some waiting time distribution.

One can think of nature randomly choosing buyers at a rate $n_b \lambda_b$ from a distribution g_b of latent buyer types with each type being a person's willingness to pay. Similarly for sellers, one can think of nature randomly choosing sellers at a rate $n_s \lambda_s$ from a distribution g_s of latent seller types with each type representing a cost or a reservation selling price. Thus, we will sometimes say loosely that the buyers and sellers are randomly arriving at the market with randomly distributed incentives and a fixed life.

Figure 2.1 provides an impression of the environment from the point of view of a subject. Shown there are realized incentives (the private orders received) by a subject over the course of an experiment. The horizontal axis is the time of arrival and the vertical axis is the price of the private offer (the analog of a "redemption value"). A parameter shift to a lower arrival rate took place about the middle of the experiment. As can be seen from the pattern, the subject faces a wide range of randomly arriving incentives. When all signals are viewed at once, as is the case in the figure, the difference in the pattern of incentives is apparent. The implications of parameters are more subtle from the subject's point of view. Only the arrivals themselves are observed by the subject without aggregation or frequency measurements. In Figure 2.1, the subject is only exposed to a change in the arrival rate and this change is not signaled by other features of the environment.

Figure 2.1: Example Arrival of Private Orders (Incentives) for a Single Subject Before and After a Parameter Shift That Reduces the Flow of Orders to the Subject



While the environment introduced here is new, the experimental literature contains suggestive departures from the classical environment. The literature is much too large for a complete review here. We do not attempt to review all of the modifications of the classical environment that exist in the experimental literature. Instead, we reference seminal departures in the direction of the environment developed here.

In (Jamison & Plott, 1997) and (Kagel, 2004), the incentives differed each period in a random fashion. In (Brewer, Jiang, & Plott, 2003), incentives were instantaneously refreshed after a trade took place, demonstrating that the price adjustment process was not due to the Marshallian path.[4] Many experiments involve incentives with multi-period longevities following the original study by (Miller, Plott, & Smith, 1977): notable examples being experiments with financial assets (Forsythe, Palfrey, & Plott, 1982), (Smith, Suchanek, & Williams, 1988) and many other experiments involving goods with “asset-like” properties (Peng & Plott, 1998).[5]

A flow environment with simulated buyers was created by (Millner, Pratt, & Reilly, 1990) for the study of contestable markets characterized by duopolists with falling average costs, but they studied only a solution from contestable market theory as opposed to a general concept of competitive market equilibrium. (Aliprantis & Plott, 1992), introduced the idea of “overlapping orders” similar to the idea of “overlapping generations” which have features similar to the random arrival markets we introduce here. [6] In the overlapping orders environment, each agent-type had a fixed period structure, say every 20 minutes, the beginning of which orders arrived that could be executed during the personal period and expired at the end of the personal period. Identical agent types operated on the same schedule with essentially identical preferences while different agent types operated on different (overlapping) period schedules. For example, in a two generation world, the periods for generation 2 started 10 minutes after the period for generation 1 started. The market never closed so at each

---

[4] Interestingly, because the units that could trade would be refreshed, the “arrival” rate of such units began to increase relative to units that could not trade. In order to accommodate this feature, Brewer, *et al* (2002) invented a “velocity adjusted” concept of demand and supply that can be viewed as a special case of the theoretical concepts developed here.

[5] (Cliff & Preist, 1998) allowed the accumulation of inventories and orders that were distributed to subjects at scheduled periods.

[6] In a much different environment, overlapping generations have been studied by (Marimon & Sunder, 1993).

instant there was a "young generation" that just received incentives and an old generation, with incentives that were getting ready to expire. Thus, the classical period structure was removed. One can think of the random arrival environment as an "overlapping order" environment only with random schedules that differ across individuals and many generations.

2.3 Market Institutions

The market organization implemented here is the multiple unit double auction with an order book invented for experimental applications by (Plott & Gray, 1990). At any instant, a buyer or a seller can submit an order consisting of a quantity, a per-unit price and an expiration time and send it to the market. Buy orders obligate the bidder to buy up to the stated quantity at the per unit price if accepted. Sell orders obligates the asker to sell up to the stated quantity at the per unit price if accepted. Orders are sent to a public order book that can be viewed by all agents and are listed in order of price from best to worst from the point of view of counterparties.

If trade is possible when an order arrives at the market, the trade is immediately executed at the existing price in the order book. That is, if a buy order arrives at a price that is higher than the lowest sell order price, the trade is executed at the sell order price. If the quantity of either side is not exhausted, the remaining amount is entered into the book.

The market exchange system was Caltech's Marketscape program. This market system operates over the web; agents can be located at different institutions or at home. The exchange system has a public market in which exchanges can take place. Each agent also has a private market in which orders are placed by the experimenters. These private markets provide the technology through which the random arrival environment is implemented.

2.4 Models and Theory

2.4.1 Temporal Equilibrium

At any given time, ***temporal competitive supply*** (TS) and ***temporal competitive demand*** (TD) curves are based on orders that exist in private order books (private incentives) at time t. These are the orders received by subjects that have not been acted upon or expired. For subjects i and j let $R^i(t, x_i)$ be the revenue that is produced by exercising the best x_i orders that buyer i finds in the private order book at time t and let $C^j(t, y_j)$ be the cost of buying the best y_j order found in seller j's order book at time t. Let P be the market price. The temporal competitive model holds that x_i is chosen to Max $[R^i(t, x_i)- Px_i]$ and y_j is chosen to Max $[Py_j - C^j(t, y_j)]$. From the optimization model, the TD and TS are always well defined for the individuals and the TD and TS are well defined at the market level as the sum of the functions for the individuals at a given market price.

From the construction above, we know that the temporal demand curve at time t is a downward sloping step function, TD(P,t), equal to the number of buyers (sell orders in private markets) in the market at time t—those that have arrived before t and have not yet either traded or were cancelled —with reservation prices above P.

Similarly, TS(P,t) is an upward sloping step function equal to the number of sellers (buy orders received in private markets) with reservation prices below P at time t. We can define a temporal equilibrium price as a P such that: TD(P,t) = TS(P,t).

One reason that prices might follow the temporal equilibrium is if traders followed zero, or limited intelligence bidding/asking strategies. Examples of such theories include (Gode & Sunder, 1993) and (Easley & Ledyard, 1993), in which traders submit multiple improving bids/asks over the longevity of an incentive, eventually revealing their true reservation price on each incentive before it expires. In (Easley & Ledyard, 1993), traders also submit limit offers based on recent trade prices market, which aides convergence. Likewise, zero intelligence robots programmed to simply reveal their reservation prices upon arriving to the market would generate traded prices that coincided perfectly with the temporal equilibrium.

2.4.2 Flow Competitive Equilibrium

Flow competitive demand (FCD) and ***flow competitive supply*** (FCS) curves, on the other hand, specify the arrival rates of buyers (sellers) with reserves above (below) a given price. Flow competitive supply and flow competitive demand reflect two components: 1) the distribution of latent reservation prices for buyers and sellers, and 2) the relative arrival rates of buyers and sellers. For a given price P, the levels of the flow competitive supply and demand curves are given by:

$$\begin{aligned} FCS(P) &= n_s \lambda_s \int_{-\infty}^{P} g_s(y)dy = n_s \lambda_s G_s(P) \\ FCD(P) &= n_b \lambda_b \int_{P}^{\infty} g_b(x)dx = n_b \lambda_b \left(1 - G_b(P)\right) \end{aligned} \tag{2.1}$$

Where λ_s is the arrival rate of individual sellers, λ_b the arrival rate of individual buyers, n_s and n_b are the number of seller-participants and buyer-participants, and g_s and g_b are the latent preferences, the distributions of reserve prices for sellers and buyers respectively.

A ***Flow Competitive Equilibrium*** (FCE) is defined by 1) a price P_{FCE} at which the arrival rate of buyers with reservation prices at or above P_{FCE} is equal to the arrival rate of sellers with reserve prices at or below P_{FCE}, and 2) a rate of trade associated with P_{FCE}. That is, the FCE is a price, P_{FCE}, and flow competitive equilibrium transaction rate V_{FCE} defined by:

$$\begin{aligned} FCS(P_{FCE}) &= n_s \lambda_s G_s(P_{FCE}) = n_b \lambda_b \left(1 - G_b(P_{FCE})\right) = FCD(P_{FCE}) \\ V_{FCE} &= n_b \lambda_b \int_{P_e}^{\infty} g_b(x)dx \end{aligned} \tag{2.2}$$

The FCE price is the price such that the flow of supply equals the flow of demand.[7] The equilibrium flow or volume is simply the FCD evaluated at the FCE price.[8]

[7] Note that the longevities of incentives do not affect FCE price.

[8] The FCE can be viewed from the perspective of theoretical ideas in finance. Close relationships exist between the environment introduced here and the theoretical financial market explored by (Goettler, Parlou, & Uajan, 2005). In a sense, their environment can be viewed as a special case of ours. The prominent features of their environment are: (i) private values that "reflect the idiosyncratic motives for trade (wealth shocks, tax exposure, hedging, or portfolio rebalancing needs);" (ii) the independent arrivals of traders drawn from known distributions; (iii) a publicly known "consensus value" of an asset, perhaps dictated by the present value of a dividend stream; and (iv) upon arrival in the market, the trader makes a decision about the type of order to place in an open order book and implicitly, the timing of the placement.

The essence of (i), (ii), and (iv) are in both our environment and in the GPR's environment. A concept of a "consensus value" as found in (iii), can be found in both, but in the environment introduced here, it emerges as a candidate equilibrium concept, the FCE, as opposed to an imposed parameter as done in GPR. While the FCE carries much of the intuition carried by the "consensus value" of GPR, it is not public information and there are both conceptual and technical differences. For example, when buyers and sellers have a common distribution of latent preferences and the arrival rates are the same, the FCE is the median of that distribution while the consensus value of GPR would be the mean. In addition, the FCE generalizes to the cases where the latent preferences of potential buyers and sellers do not arise from a common distribution and, since the FCE is closely associated with the classical competitive model, information or common knowledge about underlying parameters play no particular role.

Figures 2 and 3 illustrate graphs of FCS and FCD produced from uniform distributions of reserve prices on 0 to 1000. Figure 2.3, shows how the curves in 2 change when the rate of arrival for buyers is cut in half, while Figure 2.4 shows how FCS and FCD change when the distribution of buyers' valuations is shifted upward. Figure 2.5 illustrates how the FCS and FCD curves generalize to different distributions of incentives by using truncated normal distributions with a mean of 500f and a variance of 200f to generate the curves.

Different "types" can be captured by different latent preferences together with other attributes of private orders, such as arrival rates, private order longevities, etc., and restrictions on trading activities such as costly or limited inventory holdings, restrictions on limit/market order placement, etc. Those who need immediate cash, and thus might tender market orders, could be represented by a latent preference with probability mass at, say, zero on the latent supply together with a very short longevity for the agent receiving the associated private order. While we have not implemented this particular feature in this chapter, we call it to the attention of readers interested in the generality of the environment. We also note that the flows are additive and each type would have its own, independent distribution of latent parameters so the FCD and FCS would simply be the sum of the flows from the different types.

Figure 2.2: Flow Competitive Supply and Demand Arrival Curves with 1000 Buyer and Seller Arrivals Per Hour

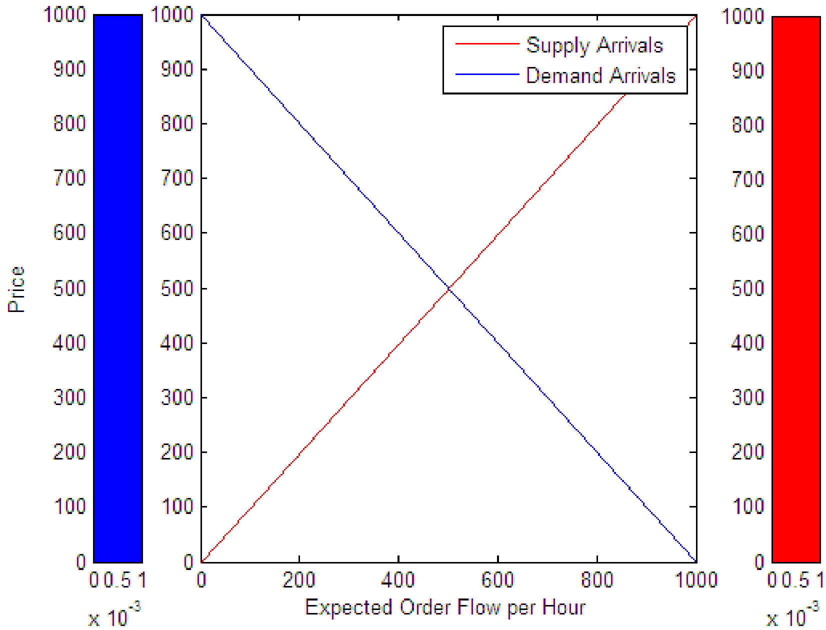


Figure 2.3: Flow Competitive Supply and Demand Arrival Curves with 500 Buyer and 1000 Seller Arrivals Per Hour

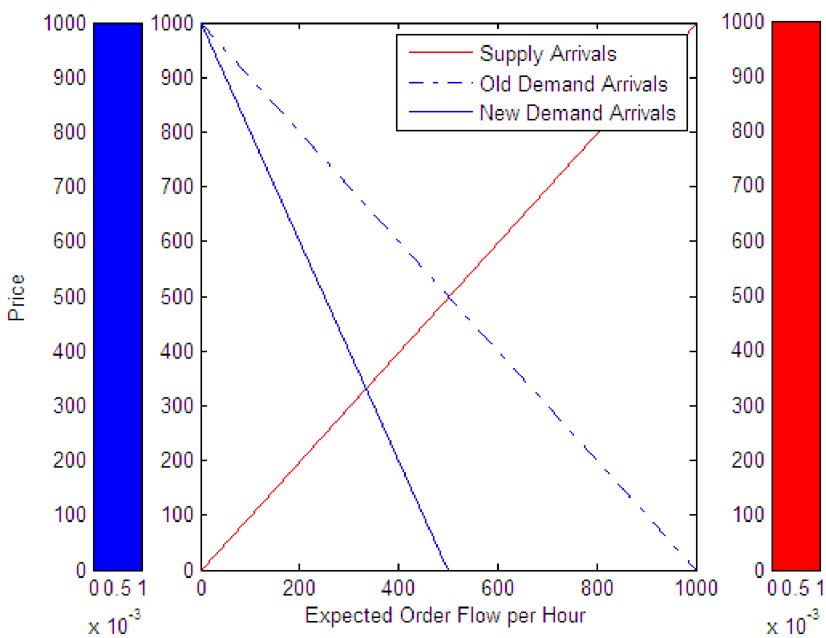


Figure 2.4: Flow Competitive Supply and Demand Arrival Curves with 1000 Buyer and Seller Arrivals per Hour and Shifted Latent Demand

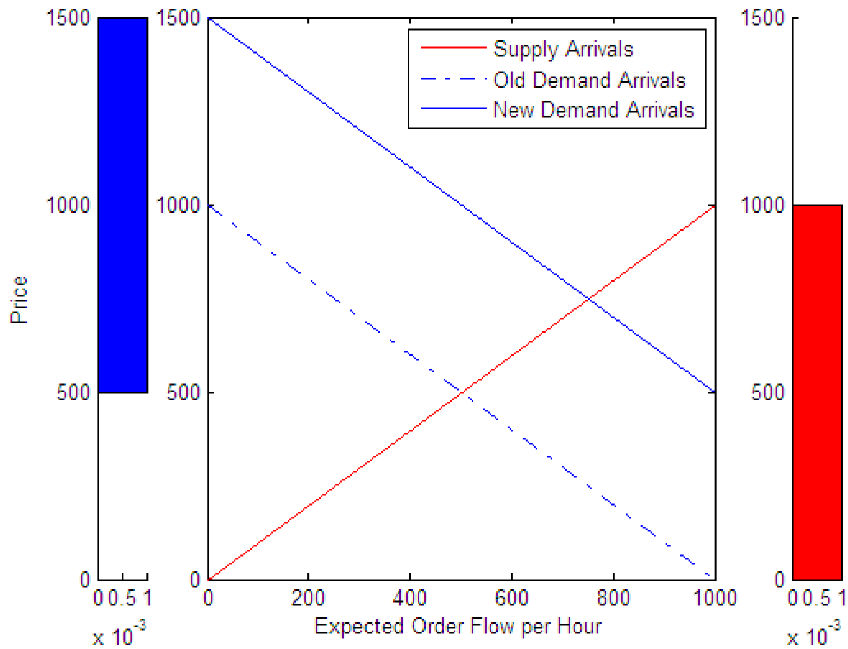
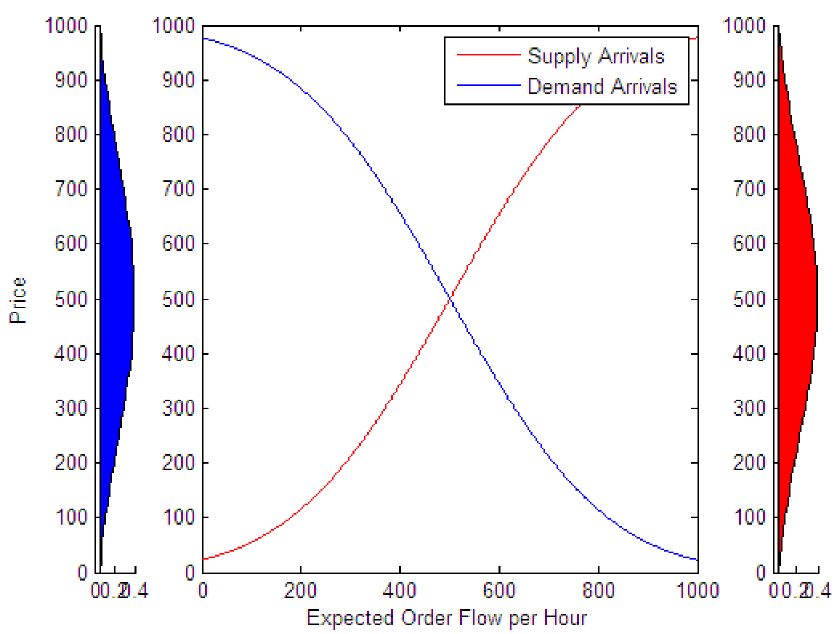


Figure 2.5: Flow Competitive Supply and Demand Arrival Curves with 1000 Buyer and Seller Arrivals per Hour and Normally Distributed Latent Incentives



2.4.3 Trader Behavior

Table 2.1 lists three different theories of how traders might behave in our environment. These theories are by no means exhaustive of the set of behaviors that subjects might exhibit, but they do represent a continuum of "trader sophistication." At one extreme are zero-intelligence models such as those presented in (Gode & Sunder, 1993) and (Brewer, Jiang, & Plott, 2003). In zero intelligence models, traders submit bids and asks at random within their budget sets, traders have no memory of past prices, incentives, and their actions are not a product of explicit utility maximization. In both of these models, traders act on each private offer individually, realizing a reservation price, then submitting a (possibly marketable) limit order between their reservation price and a price floor or ceiling, and possibly submitting additional random bids based on the same incentive at a future time.

In the middle are "limited intelligence models," like that of (Easley & Ledyard, 1993). Limited intelligence models are similar to their zero intelligence counterparts, but may include features such as memory of past prices or learning based on past offers and trades. Learning and memory causes limited intelligence traders to behave at random at first, and gradually alter their behavior over time. In (Easley & Ledyard, 1993), for example, traders submit limit offers within a price band determined by past trade prices, causing the distribution of bids and asks to become tighter over time.

Zero and limited intelligence traders only respond to realized incentives. That is, unsophisticated traders submit limit orders according to private offers they received in their private markets. Because of this, unsophisticated traders do not realize any additional surplus due to smoothing temporal imbalances in supply and demand. Moreover, prices in markets with zero intelligence traders tend not to converge (Gode & Sunder, 1993), unless they are aided by additional market institutions such as a limit order book (Aliprantis & Plott, 1992), or limited intelligence such as memory (Easley & Ledyard, 1993).

At the other extreme are theories of sophisticated or full intelligence traders. These theories come from the financial literature and deal with “dealers” or “maker makers,” who must make the market in the presence of randomly arriving market orders rather deal with “traders,” who submit both market and limit orders and have randomly arriving incentives. Full intelligence models diverge from less sophisticated models in that full intelligence traders, as in (Garman, 1976) and (Amihud & Mendelson, 1980), form (correct) beliefs about their expected future order flows and beliefs about the location of FCE prices and submit limit and market orders based on those beliefs. Neither (Garman, 1976) nor (Amihud & Mendelson, 1980) are explicit about how these beliefs are formed, merely stating that the stochastic structure of supply and demand arrivals is known to market makers. (Amihud & Mendelson, 1980) also derives that market makers’ offer prices depend on the level of dealer inventory.

Table 2.1 also compares each theory qualitatively with the observed experimental data using checks or X’s. We discuss these comparisons in greater depth in Section 6.

Table 2.1: Theories of Trader Behavior

Theory	Author(s)	Behavior	Theory Predictions	Result
Zero Intelligence	(Gode & Sunder, 1993), (Brewer, Jiang, & Plott, 2003)	Traders' bid/ask is a random function of reservation price and is independent of past prices or other incentives.	Prices closely follow the temporal equilibrium No additional surplus due to expectations is realized Efficiency depends on the number of offers made per incentive and how fast traders reveal their reservation prices	✘ ✘ NA
Limited Intelligence	(Easley & Ledyard, 1993)	Traders submit limit offers within the range of recent trade prices. Limit orders are improved over time until reservation prices are revealed by the end of the incentive's longevity.	Prices follow the temporal equilibrium No additional surplus due to expectations realized Distribution of offer prices becomes less dispersed over time	✓ ✘ ✓
Sophisticated Expectations	(Garman, 1976), (Amihud & Mendelson, 1980)	Risk neutral traders understand the random arrival structure and speculate to profit off temporal imbalances in supply and demand.	All trades occur near or at the FCE price Close to 100% of additional surplus due to expectations is realized Level of quote price negatively correlated with dealer inventory	✘ ✘ ✘
Hybrid Theories		Traders may exhibit features of multiple theories. For example, if traders are risk averse, they may speculate but not to the extent predicted by Sophisticated Expectations.	Prices will tend to be between and influenced by both the FCE and TE Some additional surplus due to expectations will be realized	✓ ✓

2.5 Experimental Procedures and Design

2.5.1 Experimental Procedures

Subjects were students recruited from Claremont McKenna College, Occidental College, and Caltech by a general request for people to put themselves in a database if they were interested in participating in experiments. The day before an experiment, invitations were sent via e-mail recruiting subjects from that database. Typically, these experiments recruited subjects from more than one school.

Subjects who reserved a spot in an experiment were sent the web location of a training program that allowed them to participate as buyers and sellers using market software typical of the market mechanism used in the experiment. Several of the students, especially those from Caltech, had prior experience with economics experiments in general. A few subjects had prior experience with market experiments in particular. Subjects were asked not to reserve a spot in experiments unless they were able to show up and participate in the whole experiment, but nearly every experiment had either subjects that were "no-shows," or subjects that dropped out before the end of the experiment. Experiments were conducted either in the evening, (around 7:00PM) or on weekends.

Subjects were given the web address of the experiment and told that they could go to the web address to get an identification number and password. Instructions were also posted at the experiment location.

Each experiment was preceded by a ten minute practice period for which subjects did not receive payment. The practice parameters were unrelated to those used in the experiment. Subjects' trading activity was monitored remotely to determine whether subjects were confused about whether they were a buyer or seller, or were confused regarding how to use their private markets. Subjects were additionally provided a phone number that they could call with any questions they had about the experiment.

The experiments started on time. At the end of the experiment subjects were told to check their mailing addresses in the database and to check our calculation of how much they earned. They were sent a check for their earnings. Subjects earned between $10 and $78 for a two hour experiment depending on performance, with most subjects earning close to an average of $40.

2.5.2 Experimental Design

A total of six experiments were conducted.[9] Each experiment featured one shift in either the distribution of buyers' redemption values/sellers' costs or a shift in the rates of arrivals. The times of these shifts occurred near the middle of each experiment and are recorded in Table 2.2. Also recorded in Table 2.2 is the length of the experiment, the number of buyers and sellers, the total number of incentives sent to buyers and sellers before and after the shift, as well as the distributions of incentives and the FCE before and after the shift. The table includes the total number of arrivals for

[9] An additional four experiments were run as pilots but were not included in this study due to the choice of parameters, computer problems during the experiment, or small sample sizes.

each side of the market and the parameterized arrival rates per person, per second. The parameterized arrival rates are the rates intended by the experimenters. Due to the random nature of the environment and computer slow downs however, the actual rates of arrivals realized in the market were typically slower than the parameterized rates. The realized rates are also listed in Table 2.2 in parenthesis. The total arrival rates per minute are the per-person arrival rates given in the table times the number of participants.

In designing the experiments, order-flow parameter files were constructed on a per person basis according to a Poisson process with redemption values/costs drawn independently from distributions known to the experimenters but not to subjects. Because of this, the experimenters did not know the actual numbers of incentives that would arrive on the buy and sell sides of the market in advance. For each buyer and seller, the experimenters recorded the time of their first and last action in their private market. The number of incentives sent to the market listed in Table 2.2 includes only those incentives that were in the market, or arrived to the market during the interval that the trader for whom they were intended was active.

Since the experiments were conducted with remote subjects, tight control over participation was impossible. Typical of internet market experiments, parametric adjustments to models were required when subjects quit the experiment after having started. In such cases, the models were recalibrated for a different number of subjects beginning from the time that the subject stopped participating. For most experiments, the adjustment made for when traders were present in the market was not important.

Only in experiment market 070414, were there drop-outs and late entrants which affected the calculation of FCE. These all occurred before the parameter shift and are illustrated in Figure 2.7, which plots the FCE price path for this experiment.

Table 2.2: Summary of Experiments

Experiment Date	071004	070606	070425	070420	070414	070208
Experience	Mixed, Moderately Experienced	Mixed, Moderately Experienced	Mixed, Mostly Experienced	Mixed, Moderately Experienced	Mixed, Moderately Experienced	*Inexperienced*
Average Earnings	approx $40	approx $40	approx $40	approx $40	approx $40	*approx $40*
School(s)	Caltech	Caltech, Oxy	CMC, Oxy	Caltech, CMC, Oxy	CMC, Oxy	*CMC*
Buyers	9	7	7	8	9*	*8*
Sellers	9	5	8	9	9*	*6*
Number of Buyer Incentives	(1677, 2152)	(1848, 1122)	(830, 3302)	(3741, 748)	(4315, 2344)	*(1520, 2225)*
Number of Seller Incentives	(1778, 2530)	(1106, 773)	(3633, 941)	(863, 2480)	(4701, 3292)	*(1124, 1607)*
	pd 1 pd 2	Pd 1 Pd 2	Pd 1 Pd 2	Pd 1 Pd 2	Pd 1 Pd 2	*Pd 1 Pd 2*
Buyer Arrival Rate	4/min (4.05/min), 4/min (2.00/min)	4/min (3.70/min), 4/min (3.31/min)	2/min (1.83/min), 8.5/min (6.72/min)	8.5/min (8.00/min), 2/min (1.22/min)	16/min (10.49/min)*, 8/min (3.79/min)	*4/min (3.62/min), 4/min (3.60/min)*
Seller Arrival Rate	4/min (4.30/min), 4/min (2.35/min)	4.min (3.10/min), 4/min (3.20/min)	8.5/min (7.00/min), 2/min (1.68/min)	2/min (1.64/min), 8.5/min (3.60/min)	16/min (10.45/min)*, 16/min (5.98/min)*	*4/min (3.56/min), 4/min (3.46/min)*
Buyer Distribution	U(273,672), U(52,451)	U(52,451), U(273,672)	U(228,1229), U(228,1229)	U(114,1115), U(114,1115)	U(631,1632), U(631,1632)	*U(273,672), U(52,451)*
Seller Distribution	U(273,672), U(52,451)	U(52,451), U(273,672)	U(228,1229), U(228,1229)	U(114,1115), U(114,1115)	U(631,1632), U(631,1632)	*U(273,672), U(52,451)*
Length (min)	45.98, 119.53	71.32, 48.48	64.83, 70.22	58.43, 68.80	58.43, 68.80	*52.53, 77.32*
Equilibrium	(473f,797), (252f,1129)	(298f, 695), (508f, 419)	(417f, 672), (1010f, 735)	(928f, 709), (357f, 572)	(1108f,2280), (1047f,1316)	*(507f,653), (292f,926)*

2.6 Results

The results section is divided into four parts. The first section merely provides a graphical overview of the results of trading. In the second section, we demonstrate that two distinct equilibria do exist in our markets and that both affect the motion of traded prices. Result 1 shows that both the Temporal and Flow Competitive Equilibria closely approximate traded prices. Result 2 illustrates how the two laws interact, with each equilibrium having a distinct pull on traded prices.

The third and fourth sections of the results discusses the role of expectations in price adjustment. Since the TE and the FCE differ in the role of expectations, we are able to quantity the role of expectations, which manifests itself in improved efficiency, the formation of bids and asks and price levels.

2.6.1 Overview

Figures 6 through 10 provide an overview of the parameters and price data. Each figure plots the supply and demand curves before and after the parameter shift alongside the price, FCE, and TE price time series. Below the price time series is plotted the volume transacted over the last 30 seconds.

Figure 2.6: Flow Competetive Supply and Demand Parameters and Results for Market 070208

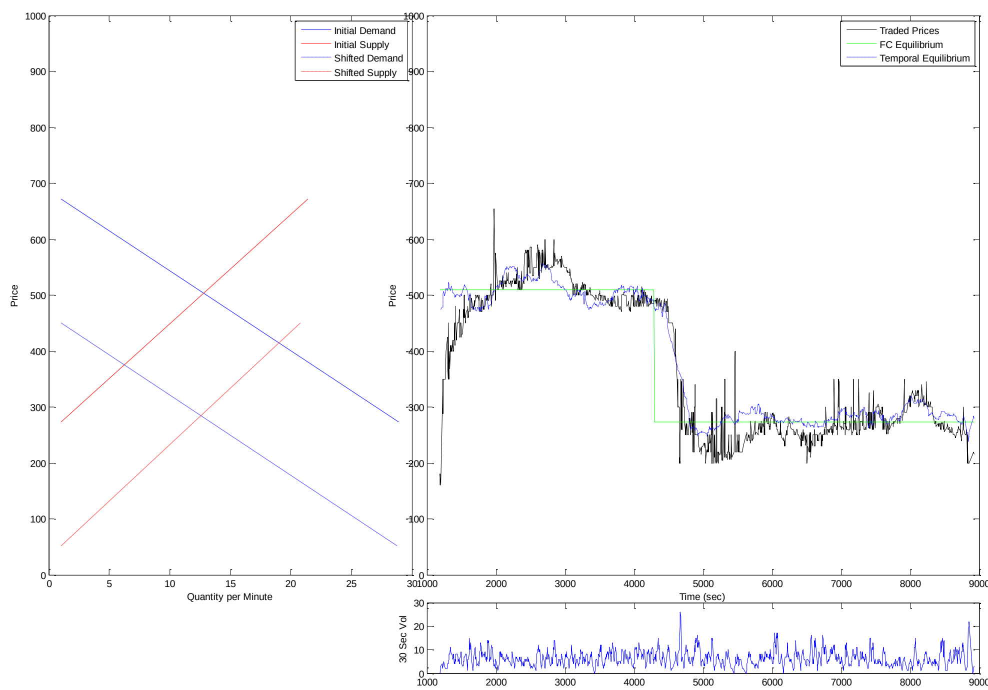


Figure 2.7: Flow Competetive Supply and Demand Parameters and Results for Market 070414

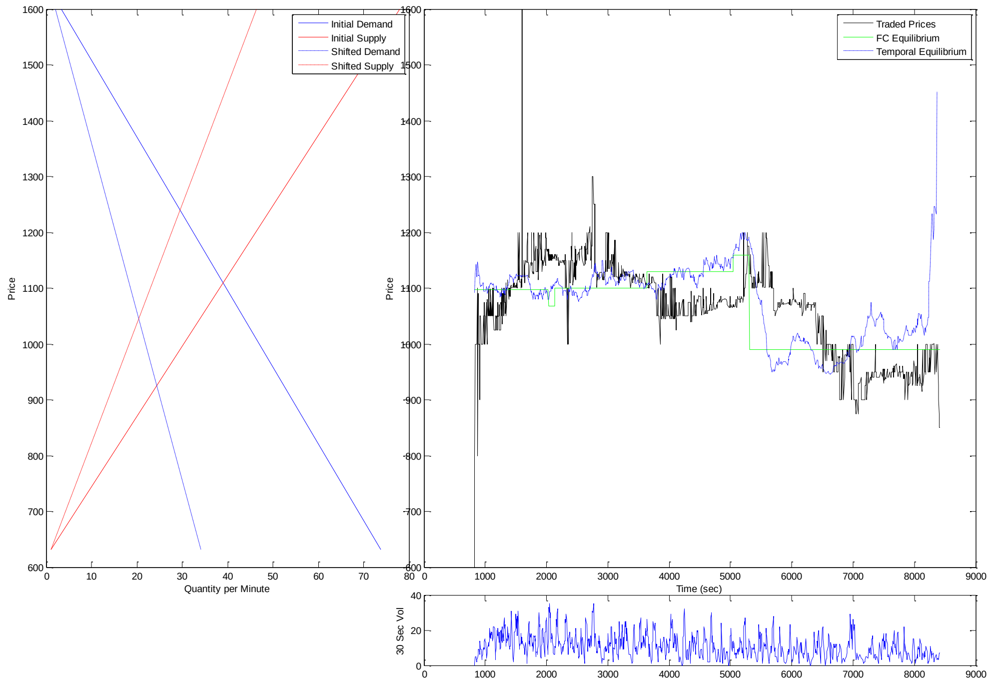


Figure 2.8: Flow Competetive Supply and Demand Parameters and Results for Market 070420

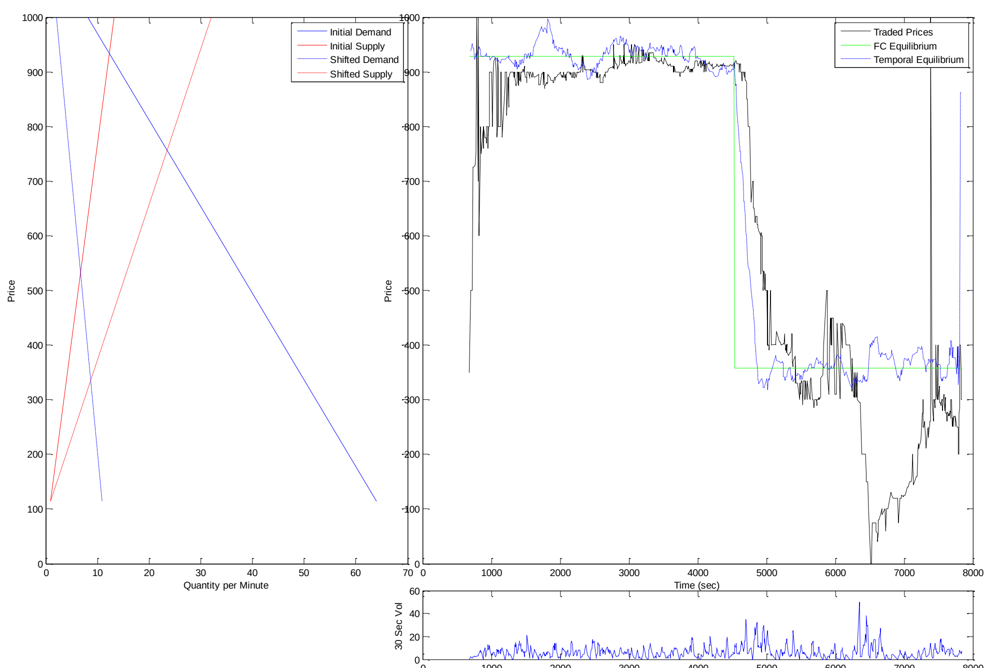


Figure 2.9: Flow Competetive Supply and Demand Parameters and Results for Market 070425

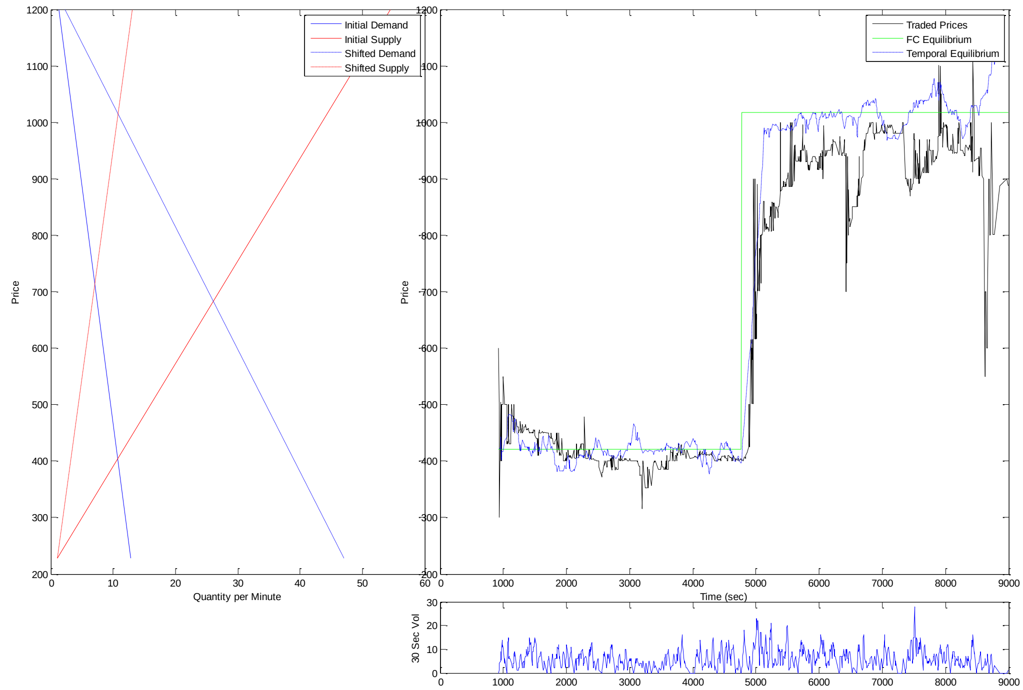
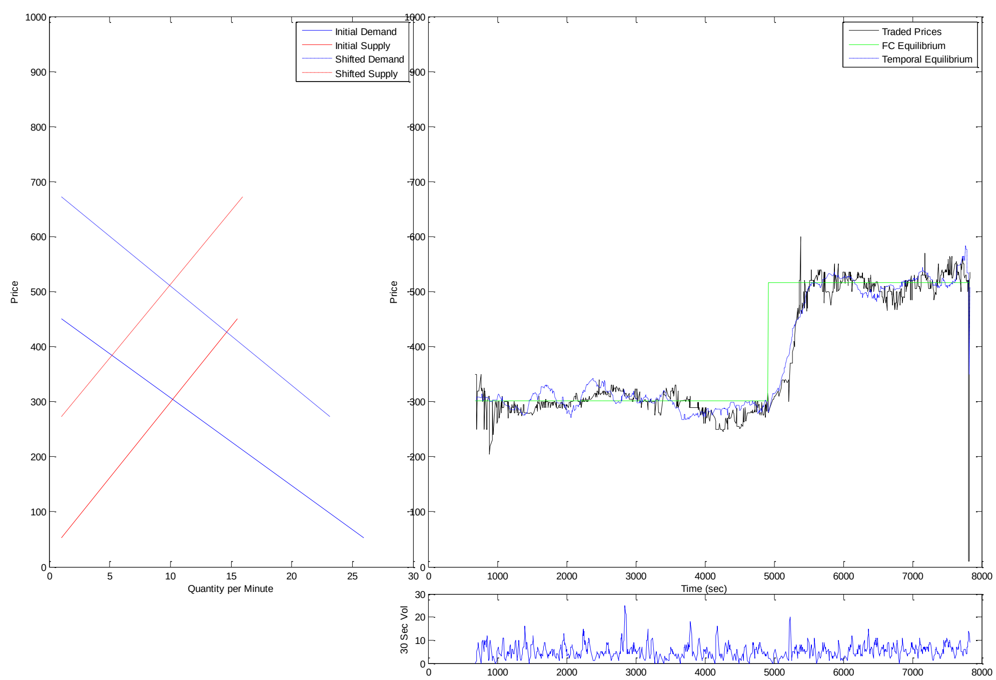


Figure 2.10: Flow Competetive Supply and Demand Parameters and Results for Market 070606



2.6.2 Price Levels

In random arrival markets, temporary imbalances in the flow of buy and sell incentives create “wandering” temporal equilibrium prices and opportunities for rational traders to profit by buying during periods of excess supply relative to the FCE and selling during periods of excess demand relative to the FCE. But are price movements affected by both equilibria? In this section we demonstrate that both laws of supply and demand do play a role in determining trade prices during an auction.

We begin with Result 1, which says that trade prices tend to form between FCE and TE prices. In Result 2, we empirically, measure the relative impact of the flow competitive and temporal equilibria on trade prices. While the FCE provides a unique pull on trade prices, trade prices are predominantly determined by TE prices.

Result 1: (i) Traded prices are distributed around both FCE and TE prices. (ii) When trade prices deviate from the FCE price, they tend to deviate in the direction of the TE price.

Support (i): The relationships among trade prices, FCE and TE are illustrated in Figures 11, 12, and 13, which also provide general impressions of the data. Figure 2.11 shows the marginal distribution of trade prices around the FCE. Figure 2.12 shows the marginal distribution of trade prices around the TE. Figure 2.13 shows the marginal distribution of deviations in the TE from the FCE.

Similarities exist among the distributions in Figures 11 and 12. Notice that the trade prices have “fat tails.” Trade prices appear to be T-distributed around the FCE and the TE. There is a statistically significant tendency for goods to be under priced relative to both the FCE and TE prices. Simple t-tests reject the null hypothesis that the mean of trade prices is equal to the FCE price at virtually any confidence level, but the economic significance, as well as the size of the under pricing in dollar terms is slight. Given a typical exchange rate of 500 francs (the currency of the experiment) =$1, a 15-20 franc price deviation represents only about 3-4 cents.

Turning to Figure 2.13, the distribution of TE prices around the FCE, has properties similar to the distribution of trade prices around the FCE. Trade prices have a higher variance than TE prices. TE prices have an estimated variance of 3654, while the estimated variance of trade prices is 8997, well over twice as high. The nature of this property is explored more closely by Result 2.

Figure 2.11: Distribution of Trade Prices Around FCE Price

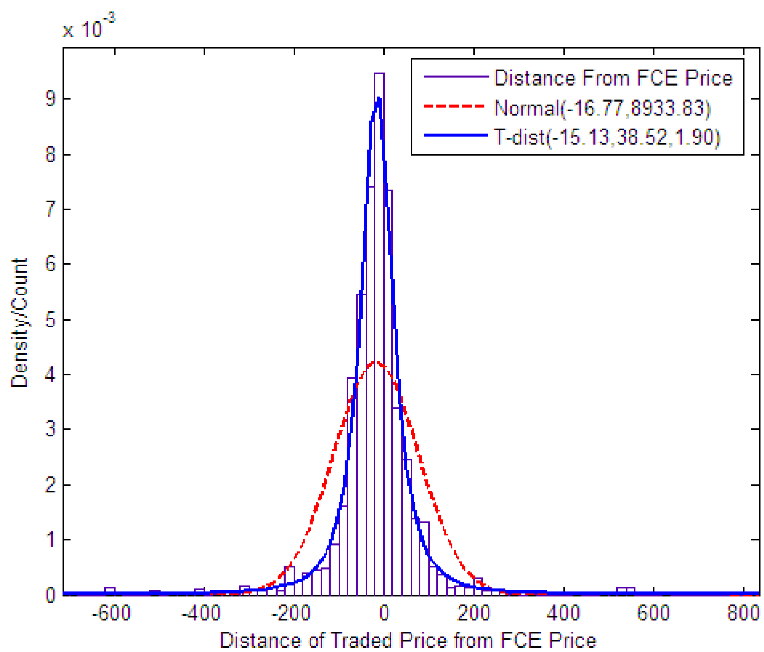


Figure 2.12: Distribution of Trade Prices Around the TE Price

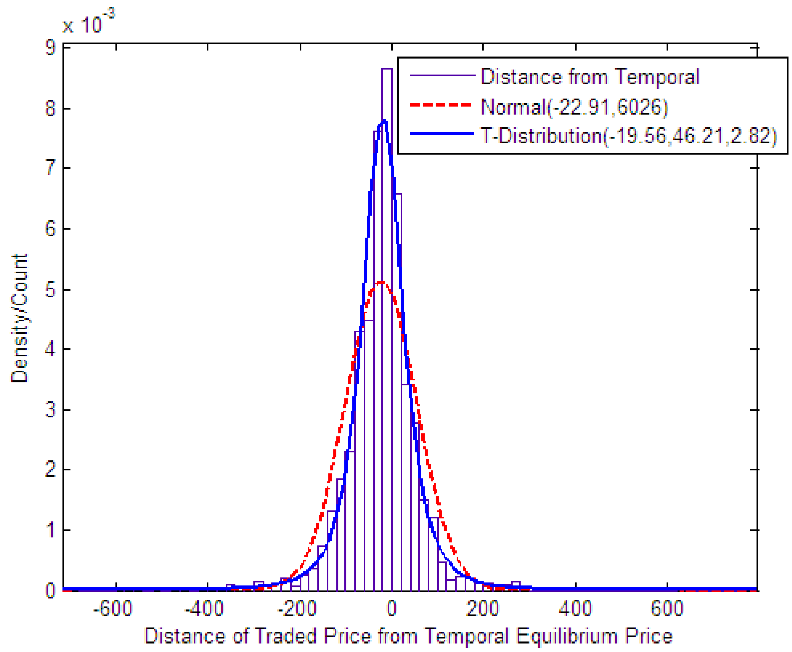


Figure 2.13: Distribution of TE Prices Around the FCE Price

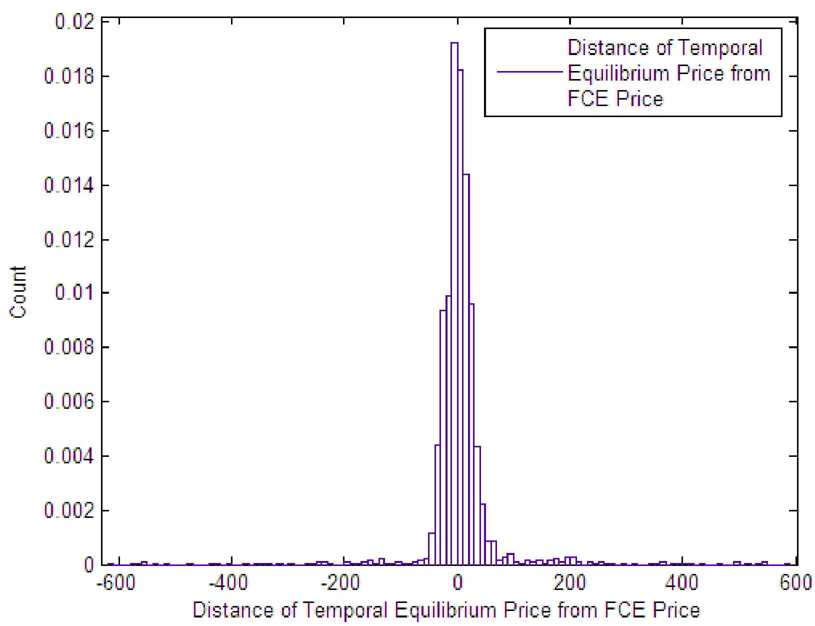
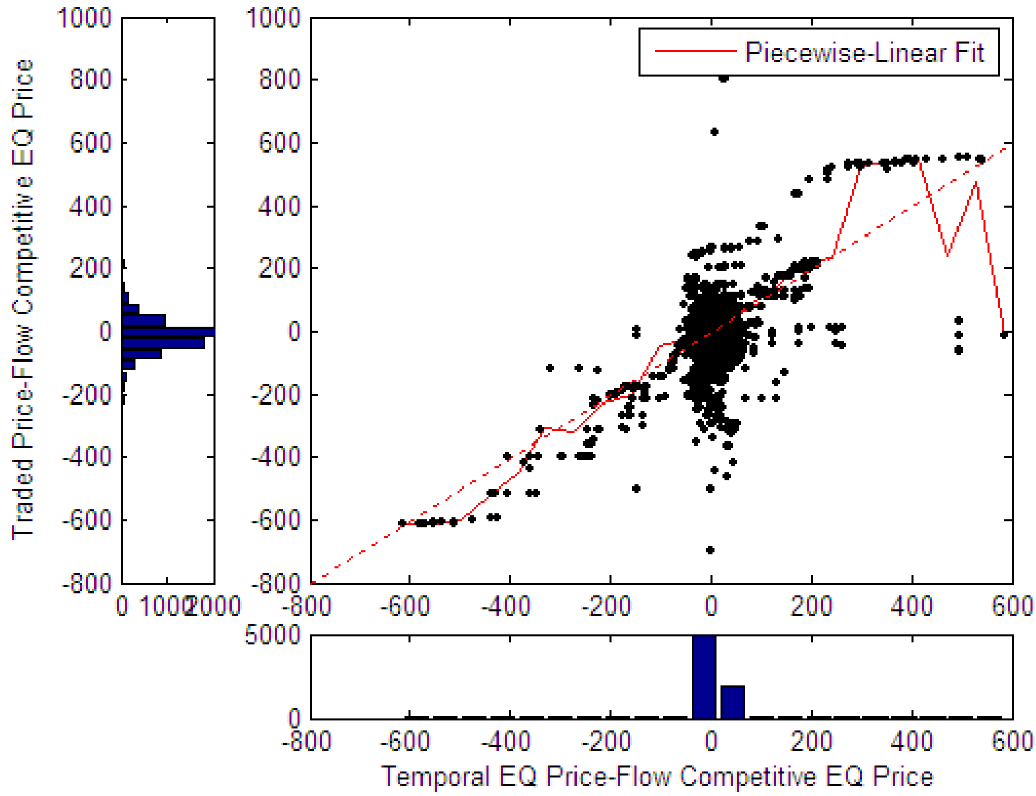


Figure 2.14: Scatter Plot of Trade Price Deviations vs. TE Price Deviations from FCE



Support (ii): Figure 2.14 illustrates the positive relationship between trade price deviations from the FCE and TE price deviations from the FCE. Across all experiments the contemporaneous correlation between these deviations is 0.6167. Notice that the relationship between temporal deviations and trade price deviations is weak when the TE is close to the FCE. This relationship becomes stronger when the TE deviations from the FCE are large in either direction

Result 2: Both the direction of temporal equilibrium prices and the direction of the FCE price influence future price movement.

Support: We use a simple least squares regression to predict future price movement based on how far away the current price is away from both the long run and the temporal equilibrium price for five different forecast horizons. Using only sections of data over which the FCE remains constant, we estimate the model:

$$P_{t+j} - P_t = \beta_0 + \beta_1(TE_t - P_t) + \beta_2(FCE - P_t) + \varepsilon_t \quad (2.3)$$

where t, indexes the trade number.

In this model, a slope coefficient of one is interpretable as “complete adjustment,” while a slope coefficient between zero and one indicates that prices are moving toward the equilibrium price, although not perfectly equilibrating.

Table 2.3 shows the results of these regressions for price changes after 1, 50, 100, 300, and 500 trades. The results indicate that prices move in the direction of both equilibria since all of the estimated coefficients are between zero and one. The magnitude of these coefficients tends to grow with the forecast horizon, suggesting that prices, at least in the short run, are “sticky” and tend to under adjust over short time periods.

A different story emerges with an examination of price changes over much longer periods of time, 300 and 500 trades in the future. At these forecast horizons, the coefficients on the distance to the temporal equilibrium price and the distance to the FCE price sum to one, but both coefficients are statistically different from one. Neither equilibrium concept appears to dominate the other. Rather, each of the two equilibria appears to have its own distinct pull on prices.

Table 2.3: FCE and TE in Forecasting Price Movement

Dependent Variable	*Explanatory Variables*				
Price Change After:	Constant	TE Price-Current Price	FCE Price –Current Price	R^2	Root MSE
1 Trade	-2.28 (0.38)	0.05 (0.02)	0.08 (0.02)	0.07	29.72
50 Trades	-9.7 (0.65)	0.34 (0.03)	0.19 (0.03)	0.31	48.97
100 Trades	-10.93 (0.75)	0.16 (0.03)	0.49 (0.03)	0.36	53.43
300 Trades	-13.09 (0.91)	0.14 (0.04)	0.87 (0.04)	0.62	50.21
500 Trades	-18.88 (1.68)	0.38 (0.06)	0.61 (0.05)	0.72	49.14

The fact that both the TE and FCE are significant predictors of price movement shows that both equilibria have independent pulls on traded prices. Moreover, since the FCE is an equilibrium concept which obtains only if rational agents form expectations about future order flow and the TE is a concept which does not involve expectations, one can take the relative coefficients on each variable as a measure of the relative importance of expectations and temporal supply and demand imbalances in price determination. According to Table 2.4, in the short run, temporal imbalances in supply and demand are equally, if not more important in determining traded prices than is expectations.

Result 3: Prices in Random Arrival markets do not converge to a single price.

Support: As support, we refer only to the Figures 6-10, which plot traded prices against TE and FCE.

Result 3 is important to note because it says that our results are not based on disequilibrium phenomenon. It is not the case that prices follow the temporal equilibrium at the beginning of the experiment and eventually level off to a constant FCE price after a period of learning and market adjustment. Nor are prices less volatile in experiments involving experienced traders. Instead, the influence of both equilibria appears to be constant throughout the entirety of an experiment.

2.6.3 Efficiency

In an environment with incentives arriving at different times, there can be multiple definitions of efficiency. Of course, each efficiency concept is closely related to the concept of experimental market efficiency first developed by (Plott & Smith, 1978). Table 2.3 reports the efficiency of each experiment relative to three different measures. The first two of these measures are directly related to expectations and hence the FCE and TE equilibriums.

The first level of efficiency reported is the ***local incentive efficiency level***. This measure compares actual surplus with the amount that would be obtained if traders submitted bids and asks equal to their reservation prices immediately upon receiving an incentive. We call this value the ***Maximum Local Surplus (MLS)*** because the market is always being cleared at a “local Walrasian” price. Under this trading strategy, there is no trade due to price smoothing or speculation, which would allow gains from trade to be realized between two traders who are not in the market at the same time.

Our second efficiency concept, the ***flow competitive rational efficiency level***, compares actual trading surplus to the level that would be obtained if all trades involving incentives that arrived prior to the shift occurred at the initial FCE price, and all of the trades involving incentives which arrived after the shift occurred at the second FCE price. We call this value the ***Maximum Flow Surplus (MFS)***.

The MLS reflects the maximum amount of surplus that would be obtained by zero-intelligence price taking agents, while the MFS reflects the amount of surplus that would be obtained by perfectly rational agents with correct expectations about future order flow. As such, we use the MLS, MFS, and actual surplus obtained in each experiment to devise a rough measure of how large a role is played by expectations in each experiment. For each experiment we compute:

$$\%\ of\ Additional\ Surplus\ Due\ to\ Expectations = \frac{(Actual\ \ Surplus - MLS)}{(MFS - MLS)} \quad (4)$$

Because the local incentive efficiency and the flow competitive rational efficiency levels are not necessarily between 0 and 1, we also devise a third measure of efficiency that does satisfy this familiar feature. This measure of efficiency compares the total gains from trade to the maximum possible gains from trade. In essence, this is the surplus that would be obtained if all the incentives, before and after the shift were aggregated as a stock, a single Walrasian price solved for, and all trades occurred at that price. We will refer to this fraction of the maximum surplus attainable as the ***clairvoyant efficiency level***, because in order for a trading mechanism to attain the maximum possible surplus, it would require a foreknowledge of future incentives flow and parameter shifts.

Hypothesis 1: The market will not realize any additional surplus due to expectations, as predicted by limited intelligence trader models.

Hypothesis 2: The market will realize close to 100% of additional surplus due to expectations, as predicted by full intelligence trader models.

Result 4: We reject both hypotheses 1 and 2. While realized surplus extraction is typically higher than the maximum local surplus that could be obtained without smoothing/speculation, not all of the available surplus from expectations is realized.

Support: As shown in Table 2.4, all experiments had levels of local incentive efficiency close to or above 100%, meaning that human subjects performed about as well or better than robots programmed to simply reveal their incentives through limit orders immediately upon entering the market would have performed.

The amount of additional surplus due to expectations that subjects were able to realize, however, differed widely across experiments. While some experiments, such as experiment 070606, were able to realize the entire surplus due to expectations, other experiments, such as experiment 070425, did not realize any. On average, human subjects were able to extract about 44% of the additional surplus available from rational speculation over all experiments.

Result 5: Experiments involving changes in arrival rates had much lower levels of surplus extraction and were characterized by incomplete convergence.

Support: Two of the three experiments involving changes in the relative rates of incentive arrivals extracted less surplus than the MLS. In one case, experiment 070425, human subjects actually managed to accumulate less rent than could have been obtained by zero-intelligence robots.

When looking at the price time series of experiments 070424 and 070425 in Figures 8 and 9 respectively, we see that prices tended to be biased away from the FCE price toward the middle of the distribution of latent incentives. Because of this, we say that the price time series of these experiments was characterized by incomplete convergence. Coincidently, the two changing rate experiments were the only experiments in which the FCE price was not equal to the mean of the distribution of latent incentives.

Table 2.4: Efficiency

Experiment Date	*Type of Shift in FCE*	*Local Incentive Efficiency*	*Flow Competitive Rational Efficiency*	*Clairvoyant Efficiency*	*Percentage of Additional Surplus due to Expectations Realized*	*(Actual Volume)/ (Predicted Volume)**
070208	Shift in distribution	136%	92%	76%	75%	1878/1582
070414	Shift in relative arrival rates	125%	87%	87%	57%	4908/3596
070420	Shift in relative arrival rates	100%	96%	64%	0%	1713/1281
070425	Shift in relative arrival rates	99%	94%	61%	-18%	1824/1407
070606	Shift in distribution	136%	102%	91%	108%	1458/1114
Average	NA	119%	94%	76%	44%	130%

* Ratio reflects speculative trades

2.6.4 Bid and Ask Placement/Improvement: Evidence of Expectations Formation

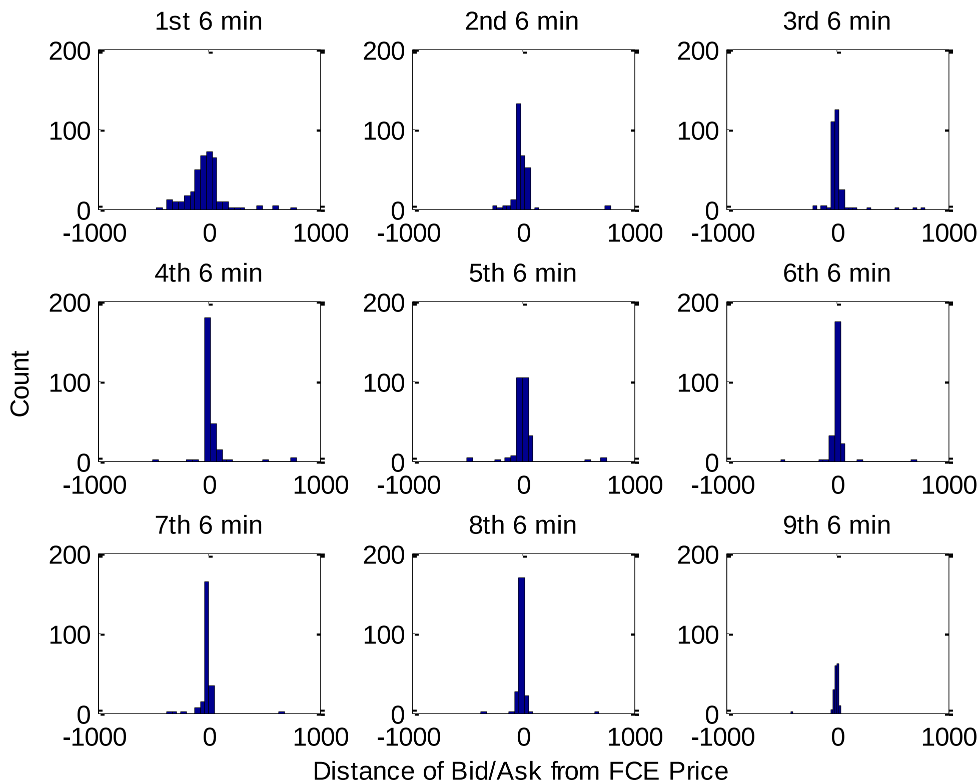
Our final area of analysis is the placement of bids and asks. Evidence of expectations formation can be seen in the distribution of new bids and asks. At the beginning of an experiment, and just after a parameter change, the distribution of bids and asks is diffuse around the FCE price. As the experiment continues, with the FCE remaining constant, the distribution of bids and asks becomes more centrally concentrated around the FCE.

If subjects acted solely on the basis of their current incentives, changes in the distribution of offer price would occur only when there was a shift in the distribution of latent incentives. The fact that there are changes in biding/asking behavior during periods of constant equilibria and the fact that new bids and asks are influenced in the direction of the FCE price suggests that expectations influence price convergence and efficiency through the supply of liquidity.

Result 6: The positioning of new bids and asks is influenced in the direction of the FCE price.

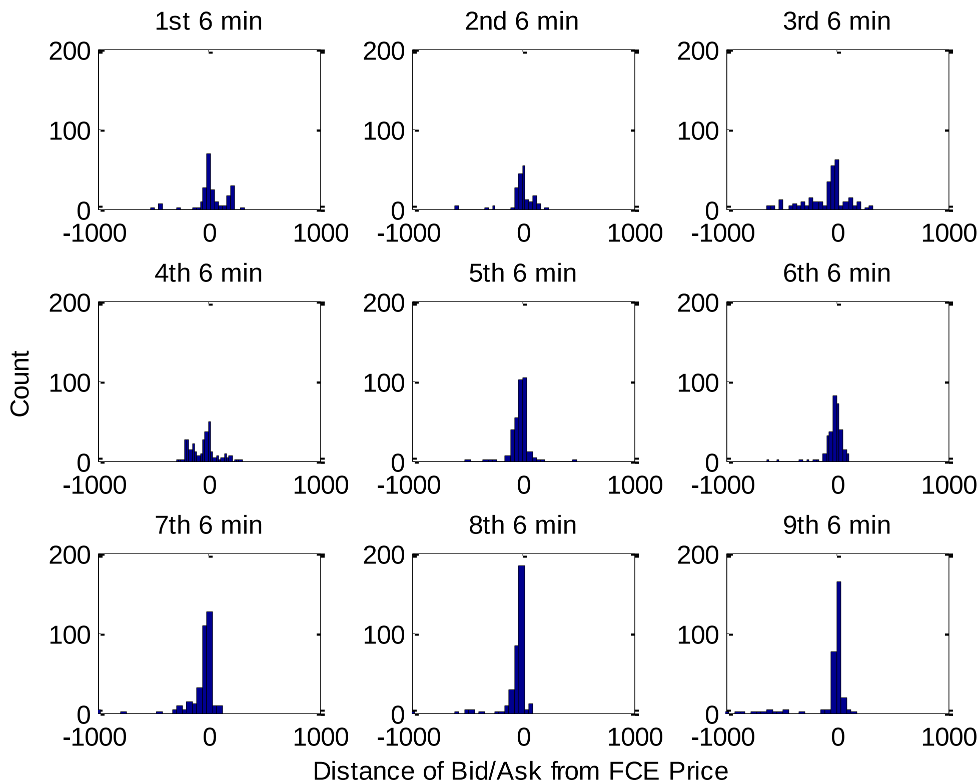
Support: As trading evolves over periods of constant FCE, a strong mode tends to appear in the distribution of offer prices accompanied by decreasing informational entropy. Figure 2.15 shows the distribution of bids and asks relative to the FCE price, divided up into non-overlapping six-minute intervals before the parameter shift. Figure 2.16 shows similar distributions of bids and asks for each 6-minute interval after the parameter shift. In both figures, we observe the formation of a large mode located close to, if not exactly on, the FCE price. The modes of the distributions in Figures 15 and 16 tend to be slightly below the FCE price. This under bidding/asking is small in dollar terms, no more than a few cents, and appears to be more prevalent during the first thirty minutes after a parameter shift than either before the parameter shift of after the first thirty minutes following the parameter shift.

Figure 2.15: Distribution of Bids/Asks from FCE Before Parameter Shift



Source: using data from experiments 070208 through 071004 excluding 070414

Figure 2.16: Distribution of Bids/Asks from FCE after Parameter Shift



Source: using data from experiments 070208 through 071004 excluding 070414

Figure 2.17 summarizes the informational content of the offer price distributions found in Figures 15 and 16. It plots the entropy of the distribution defined as:

$$E = -\sum_{x \in \chi} p(x)\ln(p(x)), \text{ where } \chi \text{ is the support of the distribution of offer prices} \quad (5)$$

Similar to variance, entropy is often interpreted as a measure of the uncertainty associated with an outcome. While variance is a measure of spread, entropy is a measure of concentration. If all of the probability of an outcome were associated with one outcome, the probability would be perfectly concentrated on that value and the entropy of the distribution would be 0. As probability becomes less highly concentrated on a single value, entropy increases. Entropy, unlike variance, does not take into account where probability is concentrated. That is, if all bids were placed at one price and all asks occurred at another, the variance of the distribution of bids and asks would depend on the size of the bid-ask spread, while the entropy of the distribution would be invariant to the size of the spread. Given both these properties, entropy is a natural measure for measuring in the "focal concentration" of the distribution of offer prices.

What we observe is that, as long as the FCE remains constant, the entropy of the distribution decreases. After the shift, there is a large increase in entropy, likely caused by divergent expectations. About thirty minutes after the shift, the level of entropy stabilizes and again begins to decrease.

Figure 2.17: The Informational Entropy of Offer Price Distributions

Source: using data from experiments 070208 through 071004 excluding 070414

2.7 Conclusions

Prices in continuous experimental double auctions are affected in the direction of two competing generalizations of the Walrasian equilibria. Human subjects are also able to achieve much higher levels of surplus extraction than would be possible from naïve trading strategies alone, though far less than 100% of the additional surplus due to expectations is realized. In particular, the amount of surplus due to expectations that traders are able to extract seems to be related to the strength of public signals regarding price changes. When shifts in the FCE price are due to changes in the distribution of latent incentives, subjects tend to extract more additional surplus due to expectations than when shifts are due to changes in the relative rates of arrivals.

Moreover, this chapter provides valuable tools for the further study of continuous markets experimentally.

Chapter 3 The Dynamics of Price Adjustment in Experimental Random Arrival and Departure Environments

3.1 Introduction

In (Alton & Plott, Working Paper1) (AP1), the multiple unit continuous double auction is generalized to an environment in which incentives to trade evolve over time. AP1 identifies two distinct competitive equilibrium concepts and demonstrates that prices in these experimental markets approach and are influenced in the direction of both equilibrium concepts. This chapter continues the analysis of AP1 by asking how this process occurs.

In this chapter, we test six competing classical models of price movement. We find that all models of price dynamics, when considered on their own, do equally well in explaining observed experimental data. However, when we nest all six models into a single equation, a clear winner emerges. Prices appear to move in direct proportion to the distance between the current price and what we will define as the “Temporal Equilibrium Price.”

Further investigation at the individual level also reveals that this price behavior stems from Marshallian features of the random arrival market. Specifically, we show that the speed with which an individual acts on an incentive is proportional to the amount of available profit from that incentive at current market prices.

The amount of profit from incentives at the current market prices is also a major predictor of bid/ask improvement and placement. Over time, bids and asks are placed closer to competitive equilibrium prices, suggesting that expectations formation may play a major role in price equilibration.

We also show that productive improvements in theory can be made by incorporating price friction, heteroskedasticity and auto correlation, and that these statistical properties of the data can be related to fundamental features of the double market auction micro-structure.

While there have been many theoretical advances in our understanding of price dynamics and stability, only recently have theories regarding price movements begun to be tested experimentally. Experimental research on price dynamics in continuous double auctions began with (Smith V. , 1962) and (Smith V. , 1965), which examined the Walrasian theory that the speed of price movement was driven by the level of excess demand. In these papers, Smith also tested the Walrasian hypothesis against his own theories of price movement, which we discuss in Section 5.2.

(Asparouhova, Bossaerts, & Plott, 2003) also study the process of price discovery in experimental double auction markets. They test modifications of the Walrasian hypothesis and find support that both the level and the derivatives of excess demand may play a role in price adjustment.

(Cason & Friedman, 1993) examine bid-ask sequences and price change autocorrelations in 30 different experimental markets and compare observations with the theoretical predictions of three non-classical models, those of: (Wilson, 1987), (Friedman, 1991) and (Gode & Sunder, 1993).

In each of the papers discussed above, double auction experiments were conducted using a “stock” of supply and demand incentives and a period structure.

Section 2 briefly summarizes the environment, equilibrium concepts and the results of AP1. Section 3 provides a summary of the experiments conducted. In Section 4, we describe some stylized facts about the time series of traded prices and point out similarities with financial micro-structure data. Section 5 we present our finding on price dynamics. We begin with a discussion of the important, albeit theoretically neglected, role of price friction, which we relate to micro-structural features of the continuous double auction market. We then examine univariate and multivariate classical theories of price dynamics using time series models. Finally, we conclude Section 5 with results supporting the Marshallian nature of our environment, and show evidence in favor of a role of expectations. Section 6 provides concluding remarks.

3.2 Trading Environment and Known Results

3.2.1 Incentive Parameter Structure (Latent Incentives and Realized Incentives)

The experiments studied here involve Random Arrival and departure (RA) environments first introduced in AP1. In a RA environment, preferences are induced though the use of private offers to buy or sell units of a good, "X," to or from the experimenter. These offers are sent to participants according to a Poisson process and last for a length of time before they expire, δ_b and δ_s for buyers' and sellers' incentives respectively. In these experiments, δ_b and δ_s are fixed lengths of time (6 minutes). The price associated with each private offer is drawn from a distribution of potential values, which we call the distribution of ***latent incentives***.

Latent buyer incentives consist of a probability density function g_b(x), where x is a price, while latent seller incentives consist of a (potentially different) probability density function g_s(y). For individual agents, draws are made from the distribution of buyer values and the distribution of seller costs according to two independent Poisson processes with intensities λ_s and λ_b respectively.

Realized incentives, as opposed to latent incentives, are the draws that are actually sent to buyers' and sellers' private order books and serve as "redemption values" and "costs." In designing experiments, λ_s is the arrival rate of private orders for each of the n_s sellers, and λ_b is the arrival rate of private orders for each of the n_b buyers.

More detailed information regarding RA environments and their relationship to traditional experimental market environments can be found in AP1, and the references cited therein.

3.2.2 Types of Equilibrium

AP1, identifies two different concepts of competitive equilibrium. While these two concepts are by no means exhaustive of the types of equilibrium that could exist, they reflect the dichotomy between supply and demand curves based on latent and realized distributions of incentives. AP1 shows that both of these equilibrium concepts have predictive power in forecasting future price movements. We briefly define and explain both types of equilibrium below.

3.2.2a Temporal Equilibrium

The Temporal Equilibrium is defined as the intersection of *temporal supply* (TS) and *temporal demand* (TD) curves, which are constructed from orders that exist, unexpired in trades' private order books at a given instant in time. The temporal demand curve at time t is a downward sloping step function, TD(P,t), equal to the number of buyers (sell orders in private markets) in the market at time t—those that have arrived before t and have not yet either traded or were cancelled —with reservation prices above P. Similarly TS(P,t) is an upward sloping step function equal to the number of sellers (buy orders received in private markets) with reservation prices below P at time t. The temporal equilibrium is then defined as a P such that TD(P,t) = TS(P,t).

3.2.2b Flow Competitive Equilibrium

Flow competitive demand (FCD) and *flow competitive supply* (FCS) curves, on the other hand, specify the arrival rates of buyers (sellers) with reserves above (below) a given price. Flow competitive supply and flow competitive demand reflect two components: 1) the distribution of latent reservation prices for buyers and sellers, and 2) the relative arrival rates of buyers and sellers. For a given price P, the levels of the flow competitive supply and demand curves are given by:

$$\begin{aligned} FCS(P) &= n_s \lambda_s \int_{-\infty}^{P} g_s(y)dy = n_s \lambda_s G_s(P) \\ FCD(P) &= n_b \lambda_b \int_{P}^{\infty} g_b(x)dx = n_b \lambda_b \left(1 - G_b(P)\right) \end{aligned} \qquad (3.1)$$

Where λ_s is the arrival rate of individual sellers, λ_b the arrival rate of individual buyers, n_s and n_b are the number of seller-participants and buyer-participants, and g_s and g_b are the latent preferences, the distributions of reserve prices for sellers and buyers respectively.

A *flow competitive equilibrium* (FCE) is defined by 1) a price P at which the arrival rate of buyers with reservation prices at or above P is equal to the arrival rate of sellers with reserve prices at or below P, and 2) a rate of trade associated with P. That is, the FCE is a price, P_e, and flow competitive equilibrium transaction rate λ_{FCE} defined by:

$$\begin{aligned} FCS(P_e) &= n_s \lambda_s G_s(P) = n_b \lambda_b \left(1 - G_b(P)\right) = FCD(P_e) \\ \lambda_{FCE} &= n_b \lambda_b \int_{P_e}^{\infty} g_b(x)dx \end{aligned} \qquad (3.2)$$

The FCE price is the price such that the flow of supply equals the flow of demand. The equilibrium flow is simply the FCD evaluated at the FCE price.

3.2.3 Known Results

In AP1, we study the predictive power of equilibrium concepts discussed above and report the following results:

AP1 Result 1: Trading in experimental RA markets generates high levels of efficiency relative to the maximum amount of surplus available. Realized surplus extraction is typically higher than the amount that could be obtained without speculation.

AP1 Result 2: Waiting times between trades are uncorrelated, and have a mean rate of transaction larger than the rate of transaction predicted by the FCE.

AP1 Result 3: The law of one price, in the sense of a constant price over time, does not emerge under conditions of a constant FCE price.

AP1 Result 4: (i) Traded prices are distributed around both FCE and TE prices. (ii) When trade prices deviate from the FCE price, they tend to deviate in the direction of the TE price.

AP1 Result 5: Both the direction of temporal equilibrium prices and the direction of the FCE price influence price movement.

AP1 Result 6: The mean squared error for price change forecasts based on the distance of current trade prices from the temporal equilibrium price and the FCE price decreases for long forecast horizons.

3.3 Experiments Studied

We use data from nine RA experiments conducted over the internet using Caltech's Marketscape software. The majority of the results in this chapter come from the first five of these experiments, reported in AP1. As a result of the original five experiments, new questions were raised and an additional four experiments were devised to answer these questions. We summarize these experiments for the purposes of this chapter below. The first five of these experiments are also described in greater depth in AP1, to which we refer interested readers.

Experiments were conducted in the evenings and on the weekends. Participants were students recruited from Caltech, CMC and Occidental College. Each experiment lasted for between one and a half and two and a half hours, and contained at least one parameter shift at some point in the experiment. Parameter shifts involved either a change in the distribution of latent incentives, or a change in the relative rates of arrival. Table 3.1 summarizes the setup of each experiment.

Most of the results and analysis presented in the following sections will focus on the first six experiments listed in Table 3.1. These experiments, involved only a single parameter shift. The remaining three experiments were designed to answer slightly different questions than the original six, and involved multiple shifts in both the FCE price and/or the distributions of latent buyer and seller preferences.

Experiments 071205 and 071208 each contain six alternating periods in which the Flow Competitive Supply and Demand functions are either both "kinked," at the equilibrium price or both "unkinked." These kinks changed the slopes of the supply and demand functions to the right of the equilibrium, but left the slopes to the left of the equilibrium constant throughout each experiment.

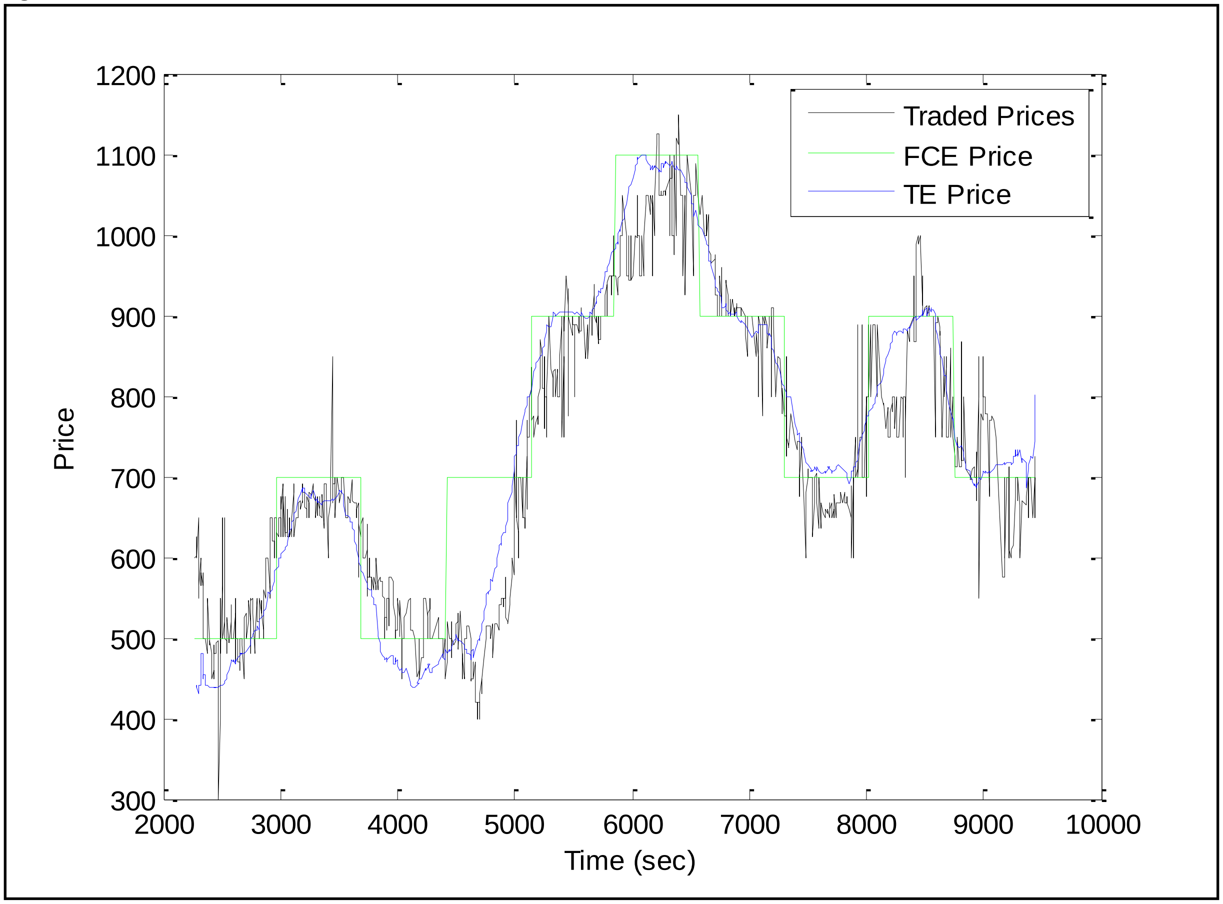
Additionally, experiments 071205, 071208 and 080201 contain ten approximately equally spaced intervals during which the FCE price remains constant. At the end of each constant-FCE interval, the FCE price is shifted up or down according to a discrete random walk by a fix amount. One realization of this process is shown in Figure 3.1, which shows the time paths of the FCE, TE and traded prices.

In the case of all experiments presented here, subjects were told that incentives in their private markets would arrive at random according to some rate and from some distribution, both of which may change over time. No other information was given to subjects regarding the stochastic processes generating incentives.

Table 3.1: Summary of Experiments

Experiment Date	080201	071208	071205	071004	070606	070425	070420	070414	*070208*
Experience	Mixed, Moderately Experienced	Mixed, Mostly Experienced	Mixed, Mostly Experienced	Mixed, Moderately Experienced	Mixed, Moderately Experienced	Mixed, Mostly Experienced	Mixed, Moderately Experienced	Mixed, Moderately Experienced	*Inexperienced*
Average Earnings	approx $50	approx $40	approx $40	approx $40	approx $40	approx $40	approx $40	approx $40	*approx $40*
School(s)	Caltech	Caltech	Caltech	Caltech	Caltech, Oxy	CMC, Oxy	Caltech, CMC, Oxy	CMC, Oxy	*CMC*
Buyers	3	15*	15*	9	7	7	8	9*	*8*
Sellers	3	15*	14*	9	5	8	9	9*	*6*
Number of Buyer	5287	5287	8120	(1677, 2152)	(1848, 1122)	(830, 3302)	(3741, 748)	(4315, 2344)	*(1520, 2225)*
Number of Seller	4720	4720	7066	(1778, 2530)	(1106, 773)	(3633, 941)	(863, 2480)	(4701, 3292)	*(1124, 1607)*
	NA	NA	NA	period 1 period 2	Pd 1 Pd 2	Pd 1 Pd 2	Pd 1 Pd 2	Pd 1 Pd 2	*Pd 1 Pd 2*
Buyer Arrival Rate	4/min	4/min	4/min (4.48/min)	4/min (4.05/min), 4/min (2.00/min)	4/min (3.70/min), 4/min (3.31/min)	2/min (1.83/min), 8.5/min (6.72/min)	8.5/min (8.00/min), 2/min (1.22/min)	16/min (10.49/min)*, 8/min (3.79/min)	*4/min (3.62/min), 4/min (3.60/min)*
Seller Arrival Rate	4/min	4/min	4/min (4.18/min)	4/min (4.30/min), 4/min (2.35/min)	4.min (3.10/min), 4/min (3.20/min)	8.5/min (7.00/min), 2/min (1.68/min)	2/min (1.64/min), 8.5/min (3.60/min)	16/min (10.45/min)*, 16/min (5.98/min)*	*4/min (3.56/min), 4/min (3.46/min)*
Buyer Distribution	U(1,600)+/-offset	alternating: U(1,600)+/-offset, and U(150,300)+/-offset+U(301,600)	alternating: U(1,600)+/-offset, and U(150,300)+/-offset+U(301,600)	U(273,672), U(52,451)	U(52,451), U(273,672)	U(228,1229), U(228,1229)	U(114,1115), U(114,1115)	U(631,1632), U(631,1632)	*U(273,672), U(52,451)*
Seller Distribution	U(1,600)+/-offset	alternating: U(1,600)+/-offset, and U(1,300)+/-offset+U(301,450)	alternating: U(1,600)+/-offset, and U(1,300)+/-offset+U(301,450)	U(273,672), U(52,451)	U(52,451), U(273,672)	U(228,1229), U(228,1229)	U(114,1115), U(114,1115)	U(631,1632), U(631,1632)	*U(273,672), U(52,451)*
Length (min)	NA	120.33	120.51	45.98, 119.53	71.32, 48.48	64.83, 70.22	58.43, 68.80	58.43, 68.80	*52.53, 77.32*
Equilibrium	300f+offset	300f+offset	300f+offset	(473f,797), (252f,1129)	(298f, 695), (508f, 419)	(417f, 672), (1010f, 735)	(928f, 709), (357f, 572)	(1108f,2280), (1047f,1316)	*(507f,653), (292f,926)*

Figure 3.1: Market-071208



3.4 Description of Data

A stationary process is a stochastic process in which the joint distribution of Y_t and Y_{t+n} is identical to the joint distribution of Y_{t+m} and Y_{t+m+n} for every m. That is, the joint distribution of n-step changes is independent of the current time or level of Y. A price process which is "converging" to predefined equilibrium, in the sense that prices are becoming closer (on average) to an equilibrium price over time, is a prime example of a non-stationary process. Such a process is by definition heteroskedastic, and has a different joint distribution of n-trade-ahead price changes for every level of the current price and time since the open of the market.

Because the time series of price changes for a converging process is, by its very nature, subject to such conditional heteroskedasticity, accurately measuring the effect of a variable or set of variables on dP requires specifying not only a mean equation for prices, but a volatility equation as well. The hope here is that we can model the time series of prices as a random function of a time series of price innovations which are themselves stationary and mean zero. That is, we seek an equation of the form: $dP_t = \mu(...) + \sigma(...) * \varepsilon_t$, where $\{\varepsilon_t\}$ is a mean zero stationary time series.

We begin by pooling the data from all experiments and describing its time series properties. Our experimental data share many of the empirical regularities commonly noted of financial data. Namely: 1) The distribution of price changes (returns) exhibit fat-tails, 2) The time series of squared price changes (observed volatility) is conditionally heteroskedastic, and 3) Price changes are negatively correlated at the first lag. We describe each of these briefly below. We do not claim that the principles at work here are the same as those generating these features in financial markets, merely that these markets bear some similarities on the surface.

3.4.1 Fat-Tails

The most commonly cited feature of financial data is by far leptokurtosis, or fat-tails. The distribution of price changes, pooled from all experiments, has an excess kurtosis of about 33, well beyond the kurtosis of the normal distribution. The distribution is approximately bell-shaped and symmetrical. Interested readers are referred to AP1 for further descriptions of price distributions.

Both conditional heteroskedasticity and the bid-ask bounce, discussed below, have been advanced as possible explanations of this empirical property.

3.4.2 Conditional Heteroskedasticity

Simply put, conditional heteroskedasticity refers to the property that extreme price changes are more likely to be accompany by further extreme price changes in the near future. Evidence of conditional heteroskedasticity can be found in Figure 3.2c-d, which plots the ACF and PACF of the squared price change series. Figure 3.2c-d shows significant auto and partial correlations up to at least the second lag and possibly higher.

In finance, this phenomenon is largely a statistical one, with little theory linking the existence of conditional heteroskedasticity to either microstructural features of markets or to the fundamentals of supply and demand. Financial econometricians typically model this volatility behavior using autoregressive models, linking the magnitude of past shocks to future volatility.

In Section 5, we attempt to model conditional heteroskedasticity in a non-autoregressive manner. That is, instead of trying to relate future volatility to past shocks, we instead try to model volatility as a function of persistent (auto-correlated) microstructural features of the double auction market.

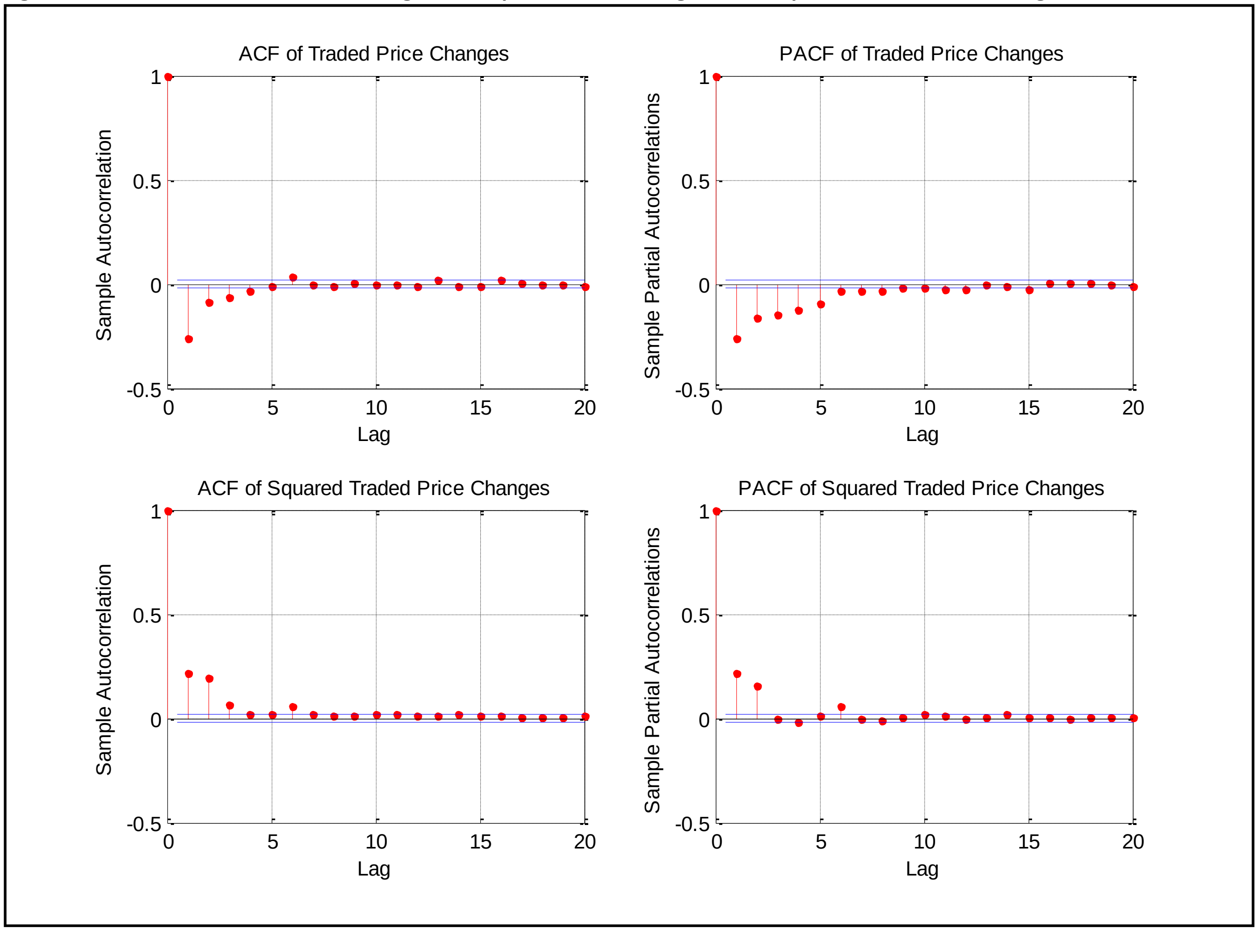
3.4.3 Negative Autocorrelation

Figures 3.2a-b show the autocorrelation and partial auto correlation functions for the mean price change series, while 3.2c-d show the autocorrelation and partial auto correlation for the squared price change series.

The first lag of the ACF is approximately 0.25, the value one might expect if prices merely bounced back and forth between fixed bid and ask prices at random (Roll 1984). At first, glance one might take this negative autocorrelation to be due to the bid ask spread as predicted by Roll, but on closer examination, the second and third lag of the ACF, as well as lags 1-7 of the PACF appear to be significant as well, a result not predicted by the Roll theory of the bid-ask bounce.

This is the only point in the chapter in which we will discuss unconditional time series properties, and we do so here only for theoretical interest. Our main interest in this chapter will be relating price changes and their squared time series to observable variables such as excess demand, current prices, etc. Each of these explanatory variables are also auto correlated and including them in a model will affect the time series structure of the model’s estimated residuals.

Figure 3.2: ACF and PACF's of Price Changes and Squared Price Changes from Experiments 070208 Through 071208



Source: using data from experiments 070208 through 071004

3.5 Results: Price Changes and the Dynamics of Price Movements

We divide the results section into three main sections. The first section of results focuses on the impact of the limit order book on both price friction and the observed volatility of price movements. ***Limit Order Book Friction*** is important for understanding the functioning of markets and evaluating theories of price movement since failing to account for friction can affect the estimated effect that market variables, such as excess demand, have on influencing future price movement. In the second section we focus on a collection of theories that we refer to as "Classical theories." These are theories that postulate about the form of the mean equation and relate expected future price movements to variables, which are observed by the experimenter but not by subjects. The third section presents results related to the Marshallian theory of quantity adjustment, the ***Probabilistic Marshallian Path***, and the role of the limit order book.

3.5.1 Limit Order Book Friction

Theories of this price adjustment are largely stylized and postulate that prices respond immediately to excess demand. In experimental limit order markets however, prices are sticky, and may not respond to excess demand immediately, as we will describe in Result 1.

Previous studies, involving simulations, have already demonstrated that a major source of this "stickiness" is the existence of the limit order book itself (Smith *et al.* 2003), (Bollerslev & Domowitz 1993), (Cohen *et al.* 1978). In order for prices to rise to a price of X in response to a change in excess demand, a transaction or cancellation must first occur at every sell-offer price listed below X. Similar adjustments to the book are needed for declining price movement. The need for existing orders to be cleared or changed effectively slows the process of price adjustment. If existing orders are not cancelled fast enough to reflect current market conditions, the market necessarily "pauses" while existing orders become engaged in transactions created by new order flow. Not only does the limit order book induce serial correlation in transaction prices, Bollerslev & Domowitz have even shown that limit order books can induce serial correlation in price volatilities as well.

The extent to which the limit order book will slow price movement will depend on the relative size of market orders compared to the size of the book itself. Interestingly, the book has the function of creating liquidity by aggregating orders over time, but this same function of liquidity provision has the side effect of slowing market adjustments.

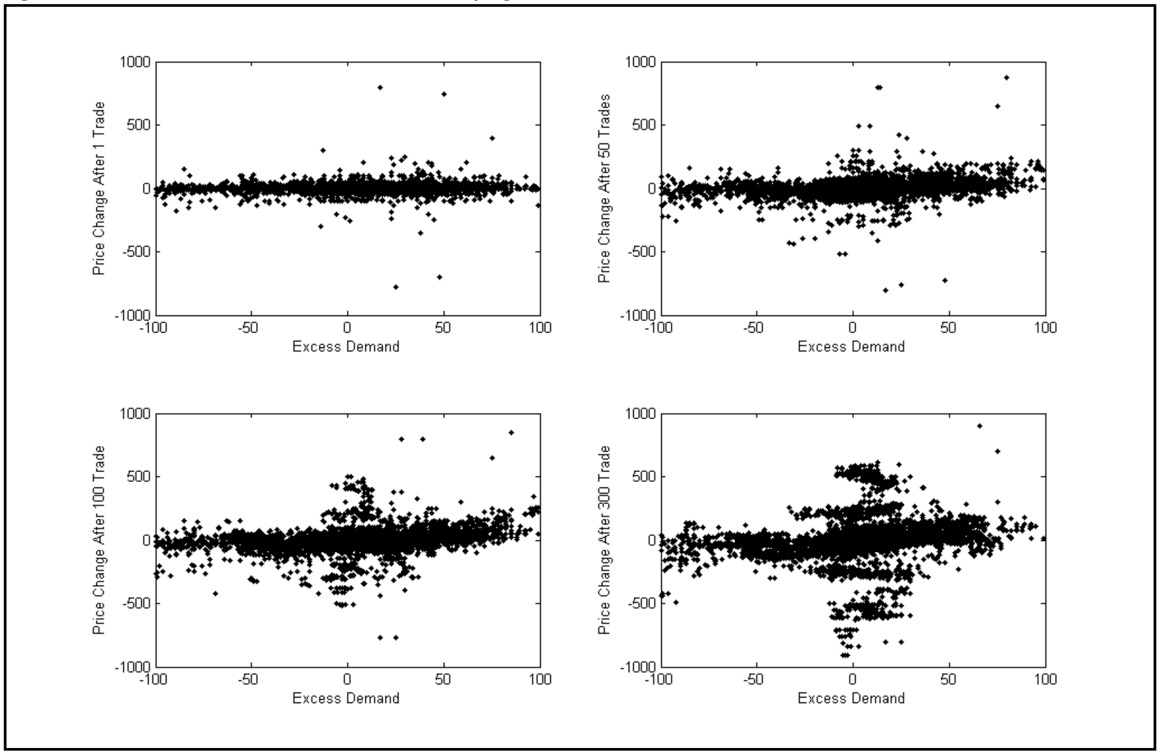
In the experiments described here, market orders are small, nearly all are less than 20 units. Most market orders, nearly 70%, are single unit orders. There are no discernible differences between the size of market orders to buy versus market orders to sell. Both the distributions of buy and sell order book lengths are non-negative, fat tailed distributions. The means and variances of the buy and sell order book lengths are 28.4, 426.2 and 16.1, 198.6 respectively. It is therefore *a priori* postulated that the friction effects of market micro structure will be large.

Result 1: Price changes are relatively insensitive to excess demand between individual trades due to limit order book friction.

Support: Figure 3.3a-d shows four different scatter plots which describe how price changes at varying levels of dt, co-vary with excess demand. Result 1 is illustrated by Figure 3.3a, which shows the price changes between individual trades. On this level,—the level at which theory most often assumes that adjustments take place—there is both visually and statistically no discernable evidence that price changes co-vary with temporal excess demand at all.

When we look at price changes over the course of 50, 100 or 300 trades (approximately 10, 20 and 60 minutes of trading respectively), the positive relationship between excess demand and price changes appears. We also begin to notice distinct “clusters” of data. This is partly because the larger the value of dt we choose, the higher the level of induced auto correlation between data points. The data also appears to cluster between experiments as well.

Figure 3.3: The Effect of Excess Demand for Varying Levels of dt



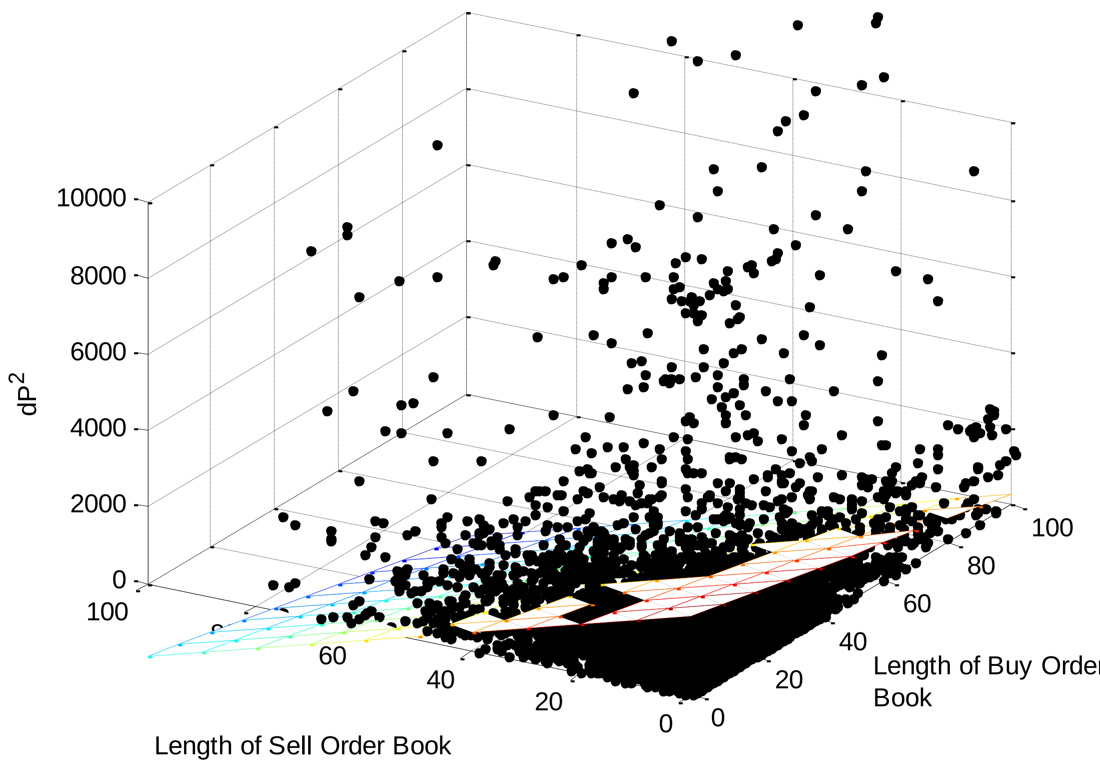
Source: using data from experiments 070208 through 071004

Unfortunately, limit order books are multi-dimensional market structures, characterized by a large number of parameters such as their level, depth and curvature. Because of the dimensionality of limit orders books, showing exactly how they slow price adjustment is difficult. Figure 3.4 shows a scatter plot of dP squared versus the lengths of the buy and sell order book. Here, we refer to the "length" of an order book as the total number of units offered for sale or purchase on that order book within 200 francs of the current trading price. The length of a book is merely one dimension of an order book and does not take into account other features such as the price level of the best offer or the depth of the market at any particular price, but, for our purposes, serves as an acceptable summary statistic. The choice of 200 francs is admittedly ad hoc, but reflects a tradeoff between including prices too far away from the market, making the measure less meaningful, and choosing a price interval so tight around the current price that there are too few units available to measure.

Also included in Figure 3.4 is an estimated hyperplane, which helps to illustrate the relationship between price volatility and limit order book friction. The regression results used to generate the hyperplane are listed in Table 3.2. As can be seen in Figure 3.4 below, the level of limit order book friction is positively related to the lengths of both order books. Large price movements/high volatility occurs systematically more often when either one or both of the limit order books is small compared to when they are large.

Table 3.2 shows the results of the regression used to create the hyperplane visible in Figure 3.4. Here, we regress squared price change on the lengths of the buy and sell order books.

Figure 3.4: Limit Order Book Friction as a Function of Order Book Depths



Source: using data from experiments 070208 through 071004

Table 3.2: Limit Order Book Friction as a Function of Order Book Depths

Variable	Coefficient	Confidence Interval
Constant	2087.11	[1495.45, 2678.77]
Length of Buy Order Book	-18.20	[-33.56, -2.84]
Length of Sell Order Book	-40.17	[-62.13, -18.22]

Source: using data from experiments 070208 through 071004

Three key features are visible in Figure 3.4. First, there are noticeably more units posted on the buy-order book than the sell order book, a feature which is true in every experiment. Second, price changes are heteroskedastic in the length of the order books, as illustrated by the slope of the estimated hyperplane drawn in the figure. The sell-order book slows upward price movement, while the buy-order book slows downward price movement. When the size of the relevant order book is sufficiently small, prices can change dramatically between trades.

The third feature visible in Figure 3.4 is that the buy-order book, while typically larger, does not increase order book friction to the same extent that the sell-order book does. As we will see later, a possible explanation for this lies in the fact that bids tend to arrive further away from current trading prices than do asks. This results in the buy order book having a steeper slope than the sell order book, and hence an asymmetric price response function.

3.5.2 Classical Models of Price Adjustment

Classical models of price change take the form:

$$\frac{dP}{dt} = f(P, ED, X_1, X_2 \ldots) \quad (3.3)$$

Where ED is excess demand at the current price and X_1 and X_2, etc. are other characteristics of the market and its supply and demand equations at a given moment in time.

Theories of the form described by Equation (3.4) can be further subdivided into two classes. The first is the classical Walrasian adjustment model, which holds that price changes are proportional to excess demand, which we take to mean the temporal excess demand at the current best ask and best bid prices[10]. That is:

$$P_{t+dt} - P_t = \alpha\left(D_t(P_t^a) - S_t(P_t^b)\right) = \alpha ED_t(P_t), \text{ where } \alpha \text{ is a positive constant} \quad (3.4)$$

This class of theories also includes a number of variations on the basic Walrasian hypothesis in which price changes are additionally influenced by the first, and possibly higher order, derivatives of excess demand. Such theories have been explored by (Asparouhova, Bossaerts, & Plott, 2003). Some variations involving elasticities and non-linearities are also explored in (Hirota, Hsu, Plott, & Rogers, 2005).

$$P_{t+dt} - P_t = f(P_t, ED(P_t), ED'(P_t), ED''(P_t), \ldots) \quad (3.5)$$

The second class of models looks at other features of supply and demand other than classical excess demand. These theories include the Excess Rent hypothesis explored by (Smith V. , 1962) and (Smith V. , 1965), the fundamentalist adjustment theory, and the theory of potential gains from trade. Each of these theories is illustrated in Figure 3.5 below. According to the Excess Rent hypothesis, price changes are

---

[10] Quantity demanded at ask price – quantity supplied at the bid price. Typically, excess demand is measured at the last trade price. The results of this section are not sensitive to this difference in definition. Nonetheless, we define temporal excess demand in this way for two important reasons. First, the traditional way of measuring excess demand may not reflect actual excess demand because it does not consider the transaction costs induced by the bid-ask spread. Second, later in the paper, we will be interested in the relative probabilities of transacting at the bid and ask price treating these prices as given. There, we will be concerned with the level of excess demand that obtains at these specific prices rather than some singular price, which may not presently exist in the market.

proportional to the area labeled ER in Figure 3.5. An alternative version of the Excess Rent hypothesis, called the Modified Excess Rent hypothesis, relies on the area labeled MER. This quantity is considered in (Smith V. , 1962) and (Smith V. , 1965) and is interpreted as the amount of surplus sellers (or buyers depending on the location of the current price) would stand to lose if all trades occurred at the current price rather than the equilibrium price.

The fundamentalist adjustment theory is a theory most often found in financial models in which there is a true "fundamental" price for an asset, which is known to a group of fundamentalist traders. Other traders in these models are typically noise or speculative traders. In this theory, price movement between trades is proportional to the distance between the current price and the fundamental price, multiplied by the proportion of traders, β, engaging in a "fundamentalist" strategy.

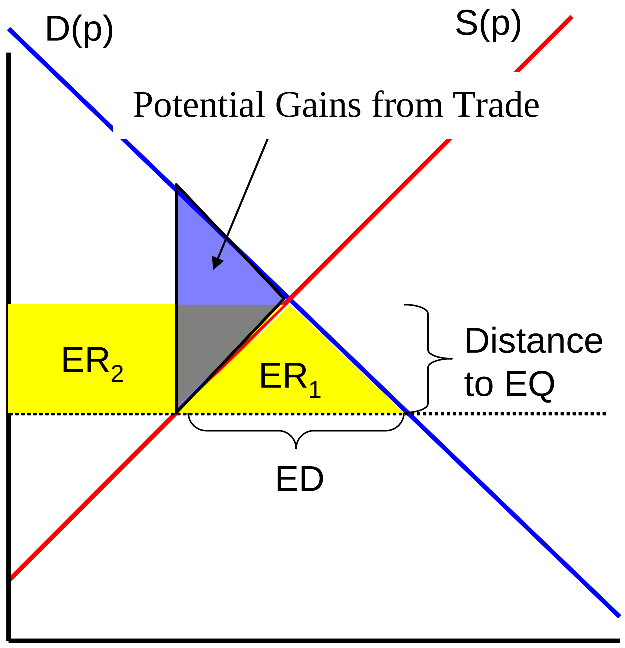
$$P_{t+dt} - P_t = \alpha * \beta(P^{Fundamentd} - P_t) + (1-\beta)\varepsilon_t \quad (3.6)$$

In our formulation of the fundamentalist adjustment model, we take the "fundamental" price to be either the temporal or the flow competitive equilibrium price. We also assume that all traders are fundamentalists.

The final model we consider is simply and intuitive model that we felt deserved consideration. The potential gains from trade hypothesis postulates that price movement is proportional to the amount of social welfare that would be lost if all trading occurred at the current price.

Since all of the areas labeled in Figure 3.5 are always non-negative, we adopt the convention of multiplying each area by (-1) when the price is above the temporal equilibrium price, and leaving the measurements positive when the current price is below the temporal equilibrium. This convention allows each variable to be positively correlated with future price changes.

Figure 3.5: Variables Used in Classical Models of Price Adjustment



The approach we take here is to first conduct a very course examination, asking which of the variables described above best explains variation in price changes in a single variable model. We then ask whether the variables described above have predictive power in the presence of each other. Essentially, we ask what is the best single variable model, and what is the best model nesting all of the theoretically important variables.

Classical excess demand is believed to affect price movement through the ***number*** of people willing to trade at a particular price. The distance to the equilibrium price, the potential gains from trade and the amount of Excess Rent however, all contain information about both the number of profitable trades as well as the ***intensity*** of the preferences driving that desire to trade.

3.5.2a Single Variable Models of Price Adjustment

Each of the single variable models considered are listed in Equations (3.7a-f). In estimating Equations (3.7a-f), we pool data from all experiments and exclude from our analysis trades that take place on opposite sides of the shift. That is, we do not use trades from the initial parameters to predict trades that will take place after the equilibrium has shifted, so the FCE equilibrium is always constant between the time at which the forecast is being made and the time that the forecasted price change will take place.

As a first pass at the data, we estimate these equations using ordinary least squares and observe the proportion of explained variance in dP as captured by the R squareds. We then build a set of more sophisticated models, which incorporates limit order book friction as well as the autocorrelation and heteroskedasticity of the residuals time series.

$$(P_{t+1} - P_t) = \beta^1{}_0 + \beta^1{}_1 ED_t + \varepsilon^1{}_t \quad (3.7a)$$
$$(P_{t+1} - P_t) = \beta^2{}_0 + \beta^2{}_1 ER1_t + \varepsilon^2{}_t \quad (3.7b)$$
$$(P_{t+1} - P_t) = \beta^3{}_0 + \beta^3{}_1 ER2_t + \varepsilon^3{}_t \quad (3.7c)$$
$$(P_{t+1} - P_t) = \beta^4{}_0 + \beta^4{}_1 WD_t + \varepsilon^4{}_t \quad (3.7d)$$
$$(P_{t+1} - P_t) = \beta^5{}_0 + \beta^5{}_1 (P^{FCE} - P_t) + \varepsilon^5{}_t \quad (3.7e)$$
$$(P_{t+1} - P_t) = \beta^5{}_0 + \beta^5{}_1 (P^{TE} - P_t) + \varepsilon^5{}_t \quad (3.7f)$$

Result 2: The naïve OLS approach concludes that the best single predictor of per-trade price changes, in terms of the proportion of explained variation in dP, is the distance between the TE price and the current price. Distance to the FCE price performs comparably well, followed by Excess. (2) All of the non-fundamental models, including the classical Walrasian model individually explain less than 1% of the total variation in price changes.

Support: For support of Result 2, we refer to the regression tables listed below. Given that the residuals of each of the naïve regressions listed 7a-7f are auto correlated and heteroskedastic, the standard errors reported by OLS, and hence the reported significance levels, are undoubtedly biased. Nonetheless, we take these estimates as crude approximations of the total correlation between market conditions and price changes, and compare the levels of R squareds (which are also known to be biased in the presence of autocorrelation) across regressions in order to provide a vague sense of what theoretical model best describes the data.

Ignoring the likely bias in R squareds, the two fundamentalist adjustment models perform about equally well. Distance to the FCE price and distance to the TE price on their own explain about 4.5% and 7% of the price change variation. The next best model, Excess Rent explains only about 0.6% of variation in price changes. In general, potential gains from trade, Excess Rent, Modified Excess Rent and excess demand all perform about equally poorly according to this measure, explaining 0.1%, 0.6%, 0.2%, and 0.3% of variation respectively.

Table 3.3: Estimation of Equations 3.7a-f

Model	Walrasian	ER	MER	PGFT	TE Distance	FCE Distance
Independent Variable	1.67***	2.47***	1.29***	1.19**	0.13***	0.08***
Constant	-0.25	-0.34	-0.02	0.04	-2.52***	-1.22***
R Squared	0.0025	0.0056	0.0014	0.0012	0.0675	0.0443

* p<.1, ** p<.05, *** p<.01

Source: using data from experiments 070208 through 071004

In order to account for limit order book friction, we add two additional terms to the mean equation. The first term is an interaction between the negative component of the independent variable at the size of the buy order book. The second is the interaction between the positive component of the explanatory variable and the size of the sell order book. By negative (positive) component, we mean that neg(X) (pos(X)) is equal to X if X<=0 (X>0) and equal to zero otherwise[11]. The logic of these terms is as follows: the buy order book limits downward price motion while the sell order book limits upward price motion. Friction impacts the effect of an explanatory variable by limiting price motion in the direction that the explanatory variable dictates that prices should move. A negative coefficient on β_2^X or β_3^X in equation (3.8a) implies that friction slows convergence when the size of the buy or sell order book is large respectively.

To account for autocorrelation in the residuals, we also include four lags of dP into the mean equation as well. We also specify a volatility equation for the residual

[11] By the sign convention of excess demand, both definitions of Excess Rent and potential gains from trade, explanatory variables are always positive when they are below the TE price and negative when they are above. The one explanatory variable which does not always obey this sign convention is the distance to the FCE price since the FCE can vary from the TE price.

time series, which we model as a function of buy and sell order book lengths and the size of the bid-ask spread. The mean and volatility equations are listed below in Equations 8a and 8b. Here, we simply write the equations in terms of a generic variable X rather than repeat the same equation for each supply and demand characteristic. For each variable, we estimate the model in 8a-8b using maximum likelihood estimation.

Examination of the Box-Ljung statistic reveals that, even after accounting for four lags of dp, there is typically still some significant auto correlation present in the first 20 lags. Examination of the ACF's and PACF's of residuals reveals that this remaining auto correlation is small in magnitude. We also compare the distribution of residuals to the quantiles of the standard normal distribution. The distributions of errors are symmetrically distributed around zero, but significantly fatter tailed than the normal distribution. For this reason, we also specify the use of Huber-White standard errors for our maximum likelihood coefficients since the Huber-White estimator is known to be robust against symmetric non-normality (See Hamilton, 1994).

$$\begin{aligned}\Delta P_t = \beta_0^X + \beta_1^X X_t + \beta_2^X neg(X_t) * BuyBook + \beta_2^X pos(X_t) * SellBook + \beta_3^X \Delta P_{t-1} + \beta_4^X \Delta P_{t-2} \\ + \beta_5^X \Delta P_{t-3} + \beta_6^X \Delta P_{t-4} + \sigma_t^X \varepsilon^X{}_t, \quad \text{for X} = \{\text{ED}, \text{ER1}, \text{ER2}, \text{WD}, (\text{P}^{\text{FCE}} - P_t), (\text{P}^{\text{TE}} - P_t)\} \quad (3.8a)\end{aligned}$$

$$\sigma_t^X = \gamma_0^X + \gamma_1^X BuyBook + \gamma_2^X SellBook + \gamma_3^X BidAskSpread, \quad \{\varepsilon_t^1\} \sim iid\ \ N(0,1) \quad (3.8b)$$

Results 3-5, describe the results of the estimation of (3.8a) and (3.8b) for each explanatory variable individually. Each of these results is particularly theoretically important in light of the naïve conclusions made in Result 2 on the basis of the biased R squared statistics found in Table 3.3 from the simple OLS regression.

Result 3 demonstrates that testing competing models of price adjustment depends on the proper specification of mean and volatility equation. Failing to properly account for price frictions, auto correlations, and heteroskedasticity (even for theories in which these quantities are not acknowledged to exist) can lead to incorrect inferences regarding the explanatory power of a particular model over another.

Result 3 states that price friction is indeed a real and measurable part of experimental double auctions. The existence of such friction, and the ability to link it to the existence of the limit order book begs the creation of new and more advanced price adjustment theories.

Results 4 and 5 confirm results from (Blooerslev & Domowitz, 1993), which were based on simulations using robot traders, for an environment containing human traders. Namely, the size and existence of the limit order book as well as the bid-ask spread can create conditional heteroskedasticity in traded price time series, providing a powerful insight into the existence of conditional heteroskedasticity.

Result 3: After adjusting for order book friction, auto correlation and heteroskedasticity, there is little difference between models in terms of log likelihood.

Support: Even though our model is estimated using maximum likelihood, we can still compare model performance using the Bayes Information Criterion (BIC) due to Schwarz (1978). The BIC is defined as $BIC = -2\ln(L) + k\ln(n)$, where n is the number of observations, k is the number of free parameters to be estimated, and L is the maximized value of the likelihood function. Assuming a flat prior, the ratio of two BIC values obtained from two different models is approximately equal to the Bayes odds ratio of the two models.

When we used R squareds to compare models in Result 2, there was a dramatic difference between the two fundamentalist models and all other models. In terms of long likelihood and BIC, however, each of the models estimated from Equations (3.8a) and (3.8b) are virtually indistinguishable from one another. Using the values of BIC listed in Table 3.4, we compute the approximate Bayes odds ratio for the best and worst performing models from Result 2, the TE price distance model and the potential gains from trade model, to be 0.998. This means that, given no prior beliefs about which model generated the observed data, the posterior odds are approximately 1 to 1. Whatever force drove price equilibration in the experiments studied here, each of the six models listed in Table 3.2 capture that force about equally well.

Often negative results are not interesting. Why bother reporting that our posterior beliefs about what theory generated the data are identical to our, non-informative, prior beliefs? We report Result 3 because, when taken together with Result 2 it, it shows how failing to account for price friction and the time series properties of experimental data can lead to false inferences regarding theory.

Table 3.4: BIC for Classical Models

Model	BIC	-2ln(L)
Classical Walrasian	-28088.7	-28185.13
Excess Rent	-28074.5	-28170.9
Modified Excess Rent	-28017.8	-28114.16
Potential gains from trade	-28045.6	-28141.99

Distance to FCE	-28074.8	-28171.25
Distance to TE	-27999.4	-28095.84

Source: using data from experiments 070208 through 071004

Result 4: Significant levels of order book friction are observed for every single-variable model.

Support: As support for Result 4, we refer to the parameter estimates of the interactions between explanatory variables and the relevant order book length listed in Table 3.5. According to the estimates in Table 3.5, 1 standard deviation of excess demand above zero will, on average, produce a 2-0.02*SOB franc increase in price between the current time and the next trade, where SOB is the current length of the sell order book. That is, each unit of depth in the sell order book slows upward price movement attributable to positive excess demand by 1/50th of a franc. Similarly, each unit of depth in the buy order book slows downward price movement attributable to negative excess by about 1/20th of a franc.

Admittedly, the model of price friction presented here leaves much room for improvement. In addition to our definition of order book depth being ad hoc, our model does not allow for non-linear effects of order book depth, or an effect of the curvature of order, which can vary considerably within and across experiments. We merely claim that limit order book friction does exist, and that it can significantly impact the explanatory power of theoretical models.

Result 5: A significant portion of heteroskedasticity is explainable by the size of the limit order books and the bid-ask spread.

Support: For support of Result 5, we refer to the results presented in Table 3.5. In each of the six classical models considered, the size of the bid ask spread is significant in predicting volatility at the .01 alpha level. We also find that the size of the buy and sell order books also tend to be significant in predicting volatility of price movements, though in all six regressions, the coefficient on the size of the buy and sell order book are oppositely signed, with the buy order book (asks) always contributing positively to volatility, while the sell order book (bids) always contributes negatively to volatility. Unfortunately, we are unable to offer an explanation for this phenomenon, merely reporting it as a statistical regularity.

Table 3.5: Maximum Likelihood Estimation of Equations 3.8a-b

Model	Walrasian	ER	MER	PGFT	TE Distance	FCE Distance
Mean Equation						
Independent Variable	2.10***	1.82***	1.77***	0.81***	0.02***	0.03***
x(Buy Order Book)	-0.05***	-0.03**	-0.04***	0.01	-0.00***	-0.00**
x(Sell Order Book)	-0.02***	-0.02***	-0.01**	-0.01**	-0.00**	-0.00***
Constant	-0.48**	-0.14	-0.33*	0.08	-0.31*	-0.56**
L1 Price	-0.36***	-0.37***	-0.37***	-0.36***	-0.36***	-0.35***
L2 Price	-0.12***	-0.21***	-0.21***	-0.21***	-0.21***	-0.20***
L3 Price	-0.10***	-0.14***	-0.14***	-0.14***	-0.14***	-0.13***
L4 Price	-0.09***	-0.10***	-0.10***	-0.10***	-0.10***	-0.10***
Volatility Equation						
Buy Order Book	0.01***	0.01***	0.01***	0.01*	0.01***	0.01
Sell Order Book	-0.02***	-0.02***	-0.02***	-0.2***	-0.02***	-0.02***
Spread	0.02***	0.02***	0.02***	0.02***	0.02***	0.02***
Constant	5.36***	5.36***	5.35***	5.36***	5.36***	5.33***
Regression Statistics						
N	6407	6407	6407	6397	6407	6397
-2 Log Likelihood	-28185.13	-28171	-28114	-28142	-28171.25	-28095.84

* p<.1, ** p<.05, *** p<.01

Source: using data from experiments 070208 through 071004

3.5.2b Multivariate Models of Price Adjustment

As we have seen, each of the univariate classical models considered has the power to predict future price movements, although there is no clear winner in terms of which theory best predicts future price movement. One possible explanation for this finding is that there exists a single “true” model among the class of classical models, and that each of the variables considered so far are highly correlated.

In estimating the nested model, we again use Equations (3.8a-b), where X_t is now a vector of all of the relevant variables, and pos(X_t) (neg(X_t)) is equal to 1 if most of the variables in X_t are positive (negative) and zero otherwise.

Result 6: When all of the theoretically important variables are included in a single nested model, only the distance to the temporal equilibrium and potential gains from trade are statistically significant in predicting price adjustment. 2) Of the two significant variables, only the distance to the temporal equilibrium price is found to be significantly positive.

Support: In support of Result 6 we simply refer to Table 3.6.

Table 3.6: The Nested Model

Variable	Coefficient
Mean Equation	
Excess Demand	0.68
Excess Rent	0.14
Modified Excess Rent	-0.85
Potential Gains from Trade	-0.68**
FCE Distance	0.00
TE Distance	0.03**
x(Length of Buy Order Book)	-0.02
x(Length of Sell Order Book)	-0.03*
Constant	-0.40*
L1 Price	-0.35***
L2 Price	-0.20***
L3 Price	-0.14***
L4 Price	-0.10***
Volatility Equation	
Length of Buy Order Book	0.01
Length of Sell Order Book	-0.02***
Bid-Ask Spread	0.02***
Constant	5.33***
Regression Statistics	
N	6397
-2 Log Likelihood	-28104.42

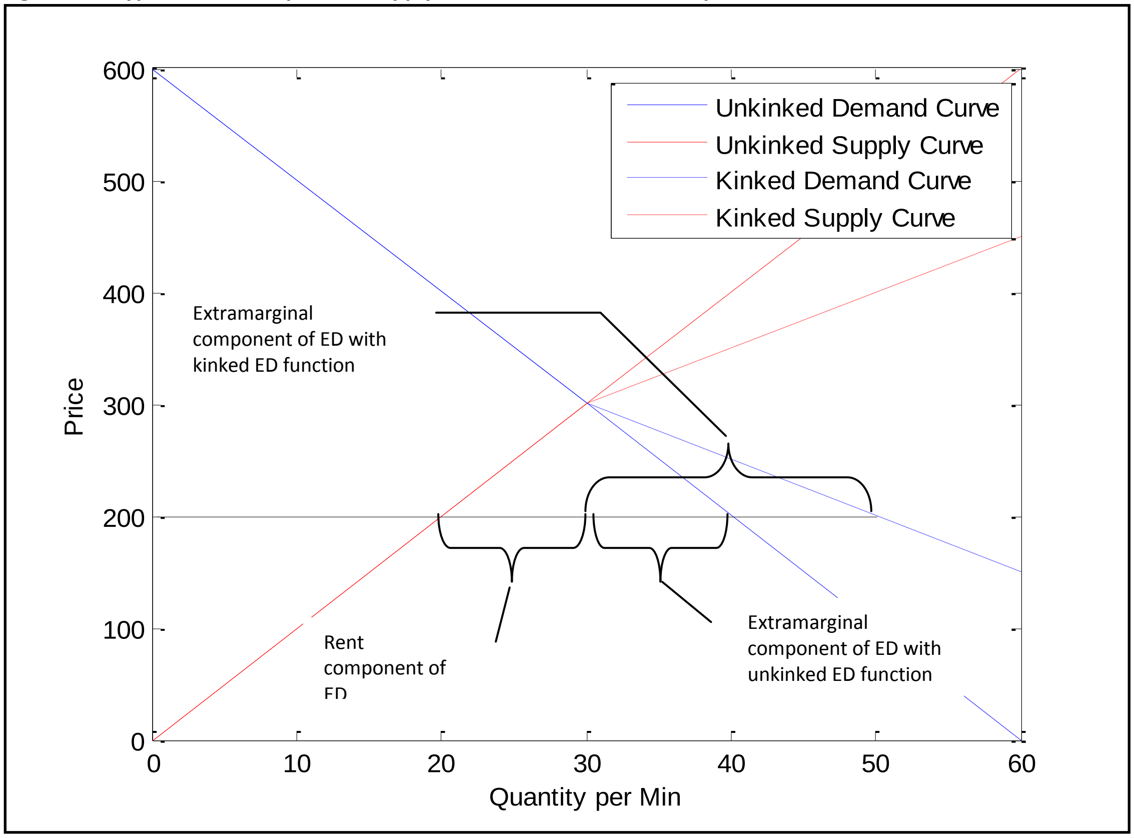
* p<.1, ** p<.05, *** p<.01
Source: using data from experiments 070208 through 071004

Experiments 071205 and 071208 were designed to better understand the relationship between the fundamentalist models and the Walrasian model. In particular, in markets with linear flow competitive supply and demand curves, like the ones we study here, there is an approximate linear relationship between temporal excess demand and the distance to the current TE price. Given Result 6, we are then left to wonder why excess demand has no effect on price motion after accounting for the distance to the Temporal Equilibrium Price.

Experiments 071205 and 071208 vary the relationship between excess demand and TE distance throughout the experiments by utilizing flow competitive supply and demand functions which alternate between kinked and un-kinked, as shown in Figure 3.6. The location of the kink is always directly at the flow competitive equilibrium price, which divides incentives between those with positive rents (to the left of the flow competitive equilibrium quantity) and those with zero rents (those to the right of the flow competitive equilibrium quantity).

Since both inframarginal and extramarginal units contribute to temporal excess demand, we also decompose excess demand into its inframarginal and extramarginal components. Notice that by locating the kink at the FCE price, we allow the relationship between the rent component of excess demand and the TE distance to remain constant (the slope of the ED function to the left), while varying the relationship between the extramarginal component and the TE distance (the slope of the ED function to the right of the equilibrium, which is either steep or shallow).

Figure 3.6: Typical Flow Competitive Supply and Demand Curves for Experiments 071205 & 071208



Result 7: Price dynamics are influenced only by inframarginal excess demand.

Support: We estimate the Walrasian version of Equations (3.8a-b) using both inframarginal and extramarginal components of excess demand as separate regressors. The results of this regression are listed in Table 3.7. To our knowledge, this is the first paper which has tried to decompose excess demand into inframarginal and extramarginal components. Accordingly, the Walrasian adjustment hypothesis holds that the coefficients on inframarginal excess demand and extramarginal excess demand will be 1) positive and 2) equal to each other. As shown in Table 3.7, only the coefficient on inframarginal excess demand is estimated to be positive. We test and reject the hypothesis that both coefficients are equal at the .01 alpha level. Each standard deviation of inframarginal excess demand results in an average price movement of 2.76 francs between trades. On the other hand, the estimated effect of extramarginal excess demand is not only insignificant, but is also negatively signed. For the first time, in Table 3.7, we do not observe a significant role of friction caused by the limit order book.

Result 7 is surprising given the theoretical importance that many authors have placed on extra-marginal units in determining the speed of price adjustments. It also suggests that price adjustment may be related to Marshallian behavior on the part of subjects. That is, if the speed at which agents act on incentives is related to the amount of available rent, changing the number of extramarginal incentives will have no impact on the behavior of subjects, and hence no impact on price dynamics.

The possibility of such Marshallian individual behavior is explored further in Section 5.3.

Table 3.7: Predicting Price Changes Based upon Inframarginal and Extramarginal Components of Excess Demand

Variable	**Coefficient**
Mean Equation	
Inframarginal Excess Demand	2.76***
Extramarginal Excess Demand	-0.67
x(Length of Buy Order Book)	0.01
x(Length of Sell Order Book)	-0.01
Constant	-0.25
L1 Price	-0.40***
L2 Price	-0.18***
L3 Price	-0.12***
L4 Price	-0.06***
Volatility Equation	
Length of Buy Order Book	-0.01***
Length of Sell Order Book	-0.00
Bid-Ask Spread	0.01***
Constant	6.51***
Regression Statistics	
N	3793
-2 Log Likelihood	-17989.42

* p<.1, ** p<.05, *** p<.01

Source: using data from experiments 070208 through 071004

3.5.3 The Marshallian Nature of RA Environments

In all of the experiments discussed here, at a given moment in time, subjects typically had more than one incentive available in their private markets. When subjects accessed their private markets each of these orders were displayed in a list in order of most to least profitable. The technology also had the limitation that subjects were unable to sort the list of available incentives by other features, such as time till expiration. A natural assumption given the structure of preference inducement used here is that subjects acted on incentives in the order of most to least profitable.

Such behavior induces what has been called the ***Probabilistic Marshallian Path***. In a deterministic Marshallian path traders are matched according to the available gains from trade, with the highest valued buyer and the lowest valued seller trading first, the second highest buyer and second lowest valued seller trading second and so on. In contrast, in a probabilistic Marshallian path traders with higher available gains from trade are not assured of trading before lower rent traders, they merely have a high probability of doing so.

3.5.3a The Marshallian Speed of Quantity Adjustment

We can still see the Marshallian theory of quantity adjustment at work by looking at individual bids and asks and ask whether the waiting time before an offer in the public market is accepted is a decreasing function of how profitable it is for the other side of the market (as a function of the offer's distance from the TE price).

For this analysis, we use the Cox proportional hazard model to estimate the hazard of a bid or ask being accepted as a function of its TE distance. The model assumes that for every offer price alive in the market at a moment in time there exists a distribution of waiting times, f(P,X,t), until that offer is accepted by the other side of the market. We can define a hazard at time t to be the instantaneous probability of an offer being accepted in the next infinitesimal moment of time, conditional on it having not been accepted up to time t.

$$h(t) = \frac{f(t)}{\left(1 - F(t)\right)} \quad (3.9)$$

We will also assume, as a consequence of Marshallian theory, that the instantaneous probability of a bid or ask being taken is shifted either up or down by the amount of rent it offers potential traders on the opposite side of the market. That is:

$$h(t) = \frac{f(t \mid X)}{\left(1 - F(t \mid X)\right)} = h_b(t)\exp\left(\theta_1 \text{TE Distance}\right) \quad (3.10)$$

Where $h_b(t)$ is the hazard rate for an incentive prices at the TE price. Cox (197?) shows that under the assumptions described above, we can estimate θ_1 without making any assumptions about the underlying distribution of failure times using partial maximum likelihood. By estimating θ_1, we can calculate relative hazard ratios:

$$HR(t) = \frac{h_b(t)\exp\left(\theta_1 X\right)}{h_b(t)} \quad (3.11)$$

This ratio tells us how much higher or lower, on average, the "instantaneous transaction rate" is for an offer a certain distance away from the TE price relative to an offer priced at the TE price. Similarly, the inverse of this ratio tells us how much longer (or shorter), in seconds, one will expect to wait for an order to be taken by pricing it a given distance away from the TE price. As one might expect, the higher (lower) an order to sell (buy) is priced relative to the TE price, the longer one can expect to wait until that order is filled.

By explicitly looking at adjustment in terms of transaction rates, we also learn more about the process of adjustment than what we have already shown. In particular, we learn that supply and demand works not only on the size and direction of price movement, but also on the *rates of transaction.*

For the purposes of our study, an offer is "born" the moment it is listed on the book as either the best bid or ask and survives until it is either taken or censored. Often, waiting times are censored because bids and asks either expire, are canceled, or are improved by a newly placed order. Such observations are said to be right censored because they did not survive long enough as the best bid or ask for a time-till-taken to be observed. These observations nonetheless contribute to the likelihood function of the Cox model, and hence to the estimation of parameters. Censored observations contribute to the likelihood in that the unobserved waiting time is known to have been larger than the length of time that the offer existed before it was censored.

Result 8: The speed of transaction for units at the bid and ask price is influenced by the amount of rent available to the opposite side of the market at that price. The higher (lower) a bid (ask) is, the faster a transaction will occur at that price.

Support: In Table 3.8, we estimate Equation (3.10), listed as Model 1, using partial maximum likelihood and report the hazard ratio and its level of significance. We also repeat the analysis for FCE distance in place of TE distance, reporting the results as Model 2, and as well as a combined model nesting all of the classical variables, reported as Model 3. We stratify each model by experiment and by whether the offer was a bid or ask. In essence, this allows the base hazard rate to vary across bids, asks and experiments.

Hazard ratios less than one, are associated with increased waiting times until an offer is accepted, while hazard ratios are associated with decreased waiting times. For example, in Model 1, we estimate hazard ratios on TE distance of about 0.8 for both bids and asks. This means that for every standard deviation a bid (ask) is below (above) the TE price, that offer will be accepted by the other side of the market only about 80% as fast as an offer placed at the equilibrium price.

Models 2 and 3 confirm that FCE distance also affects the rate at which bids and asks are accepted, although the effect of FCE distance appears to be larger in magnitude and significance for asks than for bids. The effect of TE distance on the speed at which offers are accepted also appears to be robust to the inclusion of other classical variables. Some of the these variables, such as Excess Rent and potential gains from trade also affect transaction speeds independent of the distance to the temporal equilibrium, although the direction of these effects is theoretically hard to interpret. For example, in theory, positive ER and/or potential gains from trade should be associated with upward price movement and thus an increased spread of offer acceptance at the ask price and decreased speed of acceptance at the bid price. Yet, what we observe is that Excess Rent increases the speed of both bid and ask taking, while positive potential gains from trade decreases the rate of bid and ask taking.

Table 3.8: Cox Proportional Hazard Model Results

Variable	**Model 1**	**Model 2**	**Model 3**
Bids	Hazard Ratio	Hazard Ratio	Hazard Ratio
TE Distance	0.80***	-NA-	0.79***
FCE Distance	-NA-	0.83***	0.95*
Excess Demand	-NA-	-NA-	0.98
Excess Rent	-NA-	-NA-	1.28*
Modified Excess Rent	-NA-	-NA-	1.05
Potential Gains from Trade	-NA-	-NA-	0.89*
Asks	Hazard Ratio	Hazard Ratio	Hazard Ratio
TE Distance	0.83***	-NA-	0.81***
FCE Distance	-NA-	0.83***	0.84***
Excess Demand	-NA-	-NA-	1.03
Excess Rent	-NA-	-NA-	1.17***
Modified Excess Rent	-NA-	-NA-	0.87**
Potential Gains from Trade	-NA-	-NA-	0.83***
Regression Statistics			
Observations	11152	11152	11150
Offers Accepted	6776	6776	6775
-2 Log Likelihood	-37419.678	-37433.466	-37369.312

* p<.1, ** p<.05, *** p<.01

Source: using data from experiments 070208 through 071004

While Result 8 is consistent with Marshallian behavior on the part of individuals, we are unable to relate the rent of individual incentives to the speed with which they transact in markets where subjects are allowed to hold more than one unit of inventory. This is because inventory is fungible. For the purposes of addressing the Marshallian nature of our experimental environment, experiment 080201 was designed with the restriction that traders could hold at most 1 unit of inventory, allowing experimenters to match transactions in the public market to individual incentives in traders' private markets. Result 9 states that individuals in RA environments do exhibit characteristics creating a probabilistic Marshallian path. In Section 5.3b, we look closer at the process of limit order placement to see how this probabilistic Marshallian path, combined with limit order book structure helps to stabilize trade prices close to the temporal and flow competitive equilibria.

Result 9: Incentives with higher temporal equilibrium rents were 1) accepted faster in traders' private markets 2) had higher probability of being transacted in traders' private markets, and 3) transacted faster in the public market than lower rent incentives.

Support: Support for Result 8(1-2) come from data from all experiments listed in Table 3.1, while support for Result 8(3) comes only from experiment 080201.

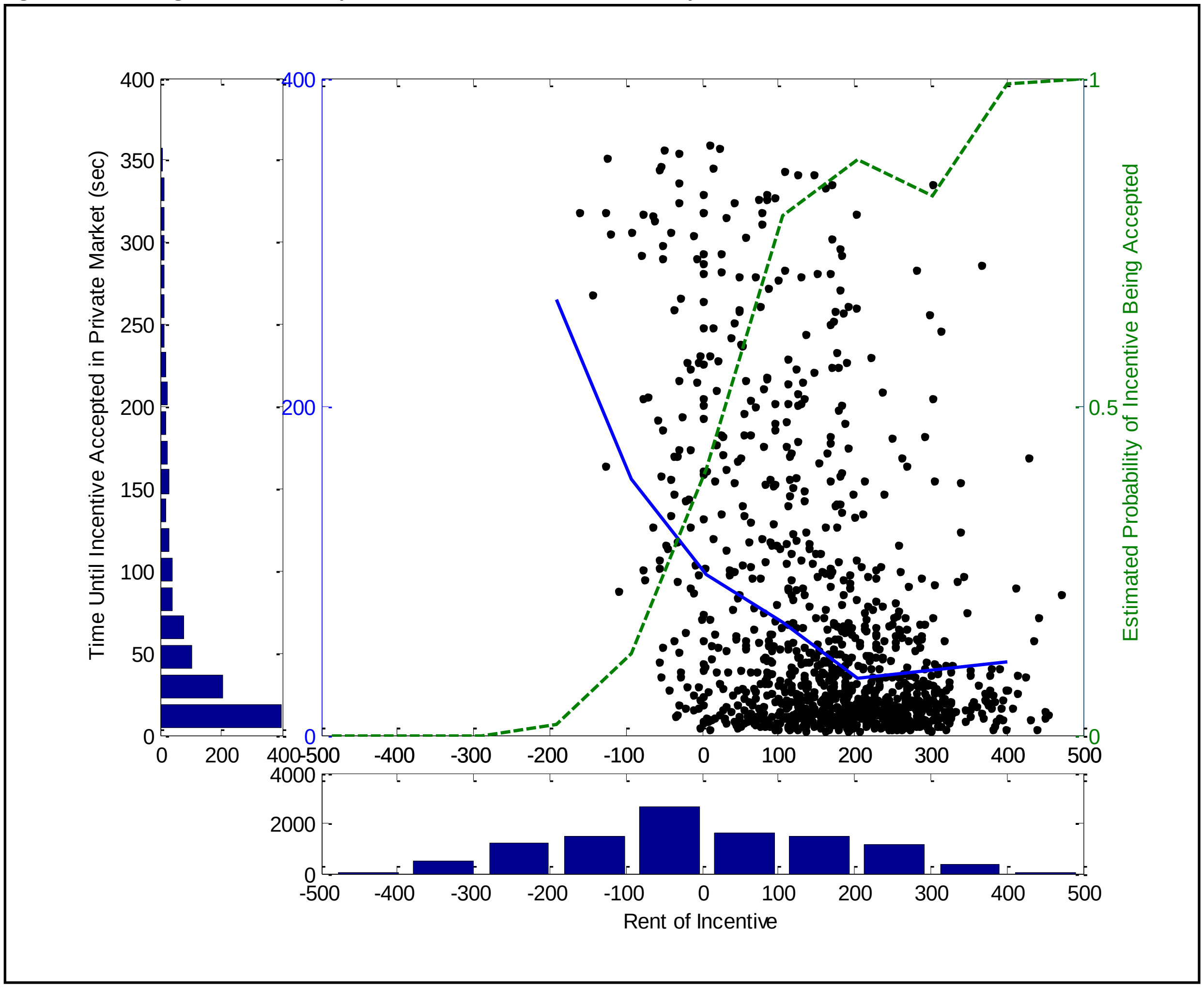
On the left y-axis, Figure 3.7 plots the waiting time between when incentives arrived in a traders' private market (for buyers and sellers) and when each incentive was accepted by the subject. Included in Figure 3.7 is a piecewise linear fit of waiting times as a function of the available rent of an incentive at the current temporal equilibrium price. On the right y-axis, Figure 3.7 also plots uniform Kernel estimates of the probability that a trader acts on an incentive as a function of its temporal equilibrium rent.

A general pattern can be seen in the scatter plot and the piecewise linear fit plotted in Figure 3.7. Incentives with large amounts of rent, in francs, at the temporal equilibrium are acted upon in subject's private market much faster than those with small rent. Units with negative amounts of rent (those that would be unprofitable if all trading were to occur at the TE price) that are still close to the TE are sometimes acted upon, but with much less frequency and typically after a longer amount of time. Also seen in Figure 3.7 is the fact that negative-rent incentives far from the equilibrium, those with less than -200 francs rent, are never accepted.

While Results 8(1) and 8(2) say that high rent incentives are more likely to enter the market before lower rent and/or non-profitable incentives, Result 8(3) says that these higher rent incentives are actually transacted faster in the public market. Admittedly a good portion of Result 8(3) may be due to the single-unit inventory restriction in market 080201, but 1) we suspect that this result is true of markets in general and 2) without the restriction of a single unit of inventory, we would be unable to measure transaction waiting times since once incentives are accepted by sellers as inventory, they become indistinguishable from one another.

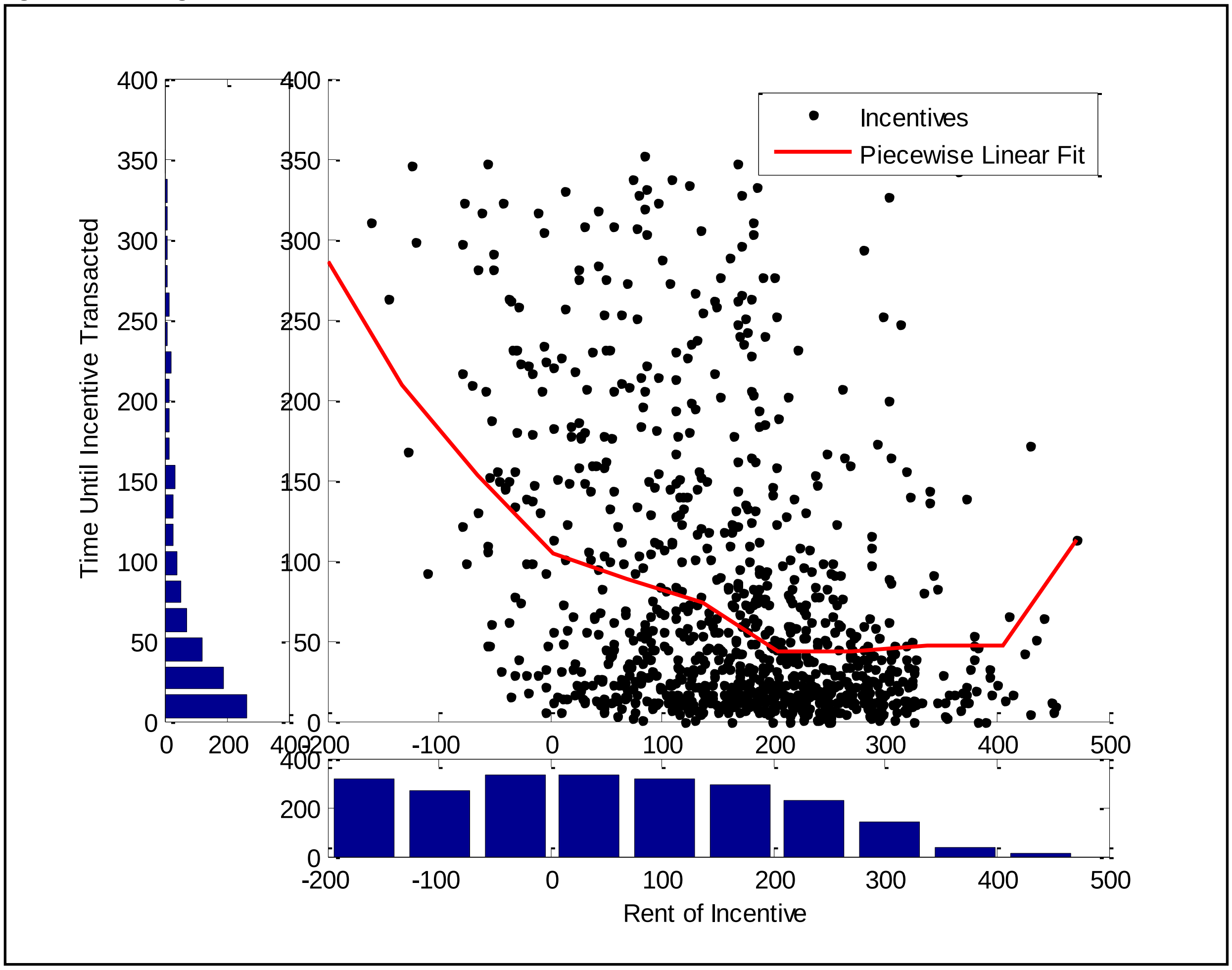
Figure 3.8, shows both a scatter plot of transaction waiting times against incentive rents, as well as a piecewise linear fit. Similar to Figure 3.7, we see a general downward sloping fit curve, individuals with higher incentives to trade do tend to enter and transact in the public market faster than individuals with lower incentives. Nearly all incentives with rent above 200 francs traded in under a minute compared to an average transaction time of about two minutes for a extramarginal incentive.

Figure 3.7: Waiting Times and Acceptance Probabilities for Incentives by Rent



Source: using data from experiments 070208 through 071208

Figure 3.8: Waiting Times until Incentives Transacted in Public Market



Source: using data from experiment 080201

3.6 Conclusions

We view this chapter as an exploratory examination of price adjustment in dynamic markets, with the hope that it will spur improvements in theories of dynamics and econometric methods for analyzing market experiments. Our findings in this direction indicate that fruitful models will require incorporating an explicit role of order-book induced price friction, heteroskedasticity and price change auto correlation. Failing to properly account for price frictions, auto correlations, and heteroskedasticity (even for theories in which these quantities are not acknowledged to exist) can lead to incorrect inferences regarding the explanatory power of a particular model over another. The size and existence of the limit order book and the bid-ask spread contribute to the occurrence of conditional heteroskedasticity in traded price time series.

We also shed light on which classical variables are most directly related to price movements. After nesting all of the theoretically important variables are included into a single model, only the distance to the temporal equilibrium is the only statistically significant variable with positive partial correlation to price changes.

The distance to the temporal equilibrium appears to be the most important classical variable for several reasons. First, price dynamics are influenced only by the inframarginal portion of excess demand. Second, the speed with which individuals act on private incentives, and transact in the market is sensitive to the amount of profit available on each incentive at the current market prices. Incentives with higher rents at current offer prices were accepted faster in traders' private markets traded quicker in the public market and had higher probability of being acted on in general.

Such findings support the hypothesis that market convergence is in part aided by the "probabilistic Marshallian Path," that is, the idea that trades will form along the Marshallian path with greater probability than would occur by randomness alone.

The distance to the FCE and TE prices are the most important variables predicting both the location of new bids and asks as well as the probability of a bid or ask improvement. Large under pricings relative to either equilibrium concept are likely to result in a faster rate of market orders on the buy side, higher bid prices, and a greater chance of bid improvement. Similarly large over pricings relative to either equilibrium are likely to result in a faster rate of market orders on the sell side, lower ask prices, and a high chance of ask price improvement.

Chapter 4 Experimental Random Arrival Markets with Competing Insiders

4.1 Introduction

We study a continuous double auction with competing insiders. Informed traders hold identical information about future order flow. Our environment differs from traditional inside information trading experiments in that previous research has tended to focus on double auctions with common valued assets. In the experiments considered here, non-informed traders are given private incentives to trade, market supply and demand is fully defined, and insiders' information takes the form of knowledge about non-insiders' current and future private incentives.

(Smith V. , 1976) argues that supply and demand in experimental double auctions creates an "induced common value" at the Walrasian equilibrium towards which prices are drawn. This is because the Walrasian equilibrium represents a price at which speculators can buy units below and sell units above to make a profit, similar to a common valued asset. As this chapter will show, the similarities between a pure common value double auction and one with a supply and demand induces Walrasian equilibrium end there.

In a common value environment, asymmetric information held by insiders is incorporated into prices through cumulative signed order flow (Kyle, 1985), (Glosten & Milgrom, 1985), (Copeland & Galai, 1983), (Huang & Stoll, 1997). In theory, this is because of two assumptions. First, it is typically assumed that the market is made by (an) uninformed market maker(s). Second, it is also assumed that traders with asymmetric information will always initiate trades through market orders in an attempt to hide their information from market makers.

In this environment we ask three questions. First, does the information held by competing insiders get reflected in informational efficiency and prices? Second, is information held by insiders reflected in the inventories of non-insiders? Third, how is insiders' information transmitted?

4.2 Background and Trading Environment

(Forsythe & Lundholm, 1990) examine a trading environment in which insiders are asymmetrically informed about the dividend payment of a risk asset. They find that trading in such markets can achieve a rational expectations equilibrium provided traders have sufficient trading experience and the structure of dividend payments are commonly known.

(Holden & Subrahmanyam, 1992) and (Back, Cao, & Willard, 2000) study a theoretical environment in which multiple insiders all have the same information. They show that when such is the case, there does not exist a stable equilibrium trading strategy among competition insiders. If all insiders are equipped with identical information, all insiders will rush into the market to grab informational rents, pushing prices to the full information price and exhausting informational rents.

(Kyle, 1985), on the other hand, shows that when information is held about a common liquidation value by a single insider, then the insider will act on his information gradually, accumulating inventory, and revealing his information through signed order flow linearly over time.

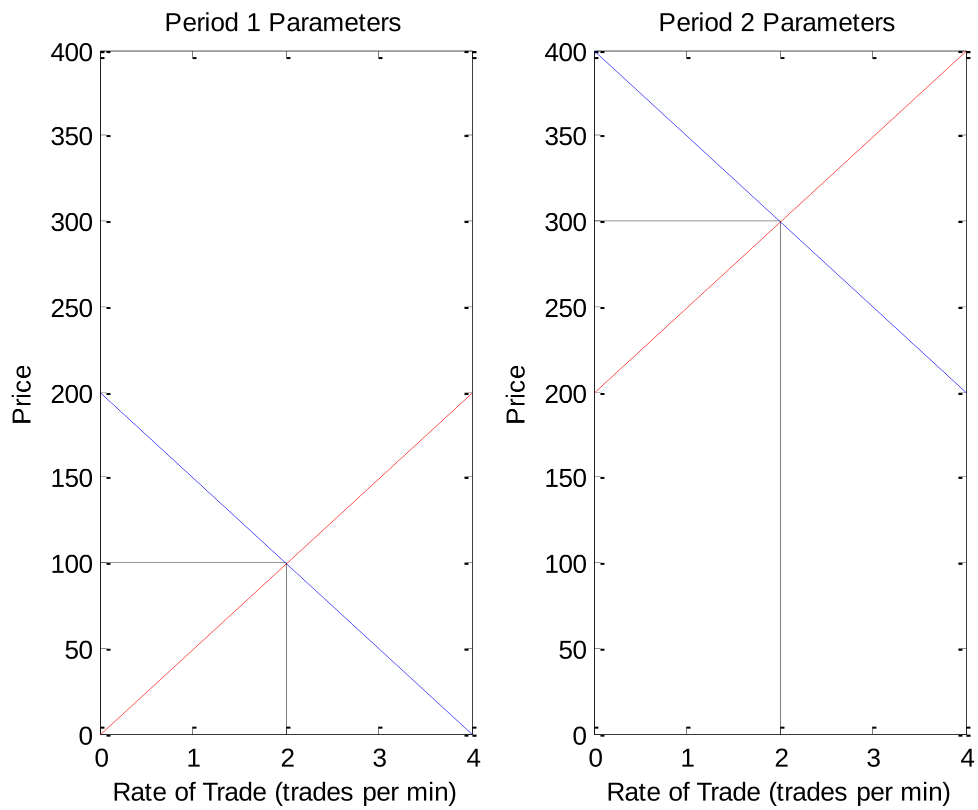
(Miller, Plott, & Smith, 1977) study an environment in which supply and demand parameters shift at random between seasons. In their experiments, some traders could become informed about future supply and demand. They find that intertemporal speculation between seasons reduces price differences in both seasons towards the intertemporal competitive equilibrium.

The trading environment we study here is a modification of the Random Arrival (RA) market found in (Alton & Plott, Working Paper1) and (Alton & Plott, Working Paper2). An important feature of RA markets is the Flow Competitive Equilibrium (FCE) price, which is an induced common value similar to the “consensus value” of (Goettler, Parlou, & Uajan, 2005). Buyers and sellers arrive to the market each having private valuations which are symmetrically distributed around the FCE price. That is, each trader’s valuation for the asset is determined both by a common value and an idiosyncratic component. Idiosyncratic components of traders’ valuations provide incentives to trade similar to “noise traders.”

Uninformed traders receive a stream of private offers to buy or sell shares of an asset, “X,” to or from the experimenter. These offers are sent to participants according to a Poisson process and last for 6 minutes before they expire. The price associated with each private offer is equal to the FCE price, plus or minus a random amount drawn from a distribution of potential values.

Informed traders, on the other hand, have no private markets and hence no idiosyncratic reasons for trade. Their payoff is based solely on their ability to buy low and resell high using their inside information. Insiders know the rate of arrival and distribution of incentives of the uninformed traders. Using this information, insiders can compute supply and demand curves and equilibrium prices. For example, if private offers to buy and sell arrived to the market at a rate of 4 offers per minute, and the offers were distributed uniformly between 0 and 200 for the first half of the experiment and uniformly between 200 and 400 for the second half. Figure 4.1 shows this graphically. The way in which supply and demand changes in these experiments is similar to (Miller, Plott, & Smith, 1977), which studies intertemporal competitive equilibrium in markets with random, seasonal fluctuations in demand and traders can purchase “foreknowledge” of future demand and supply.

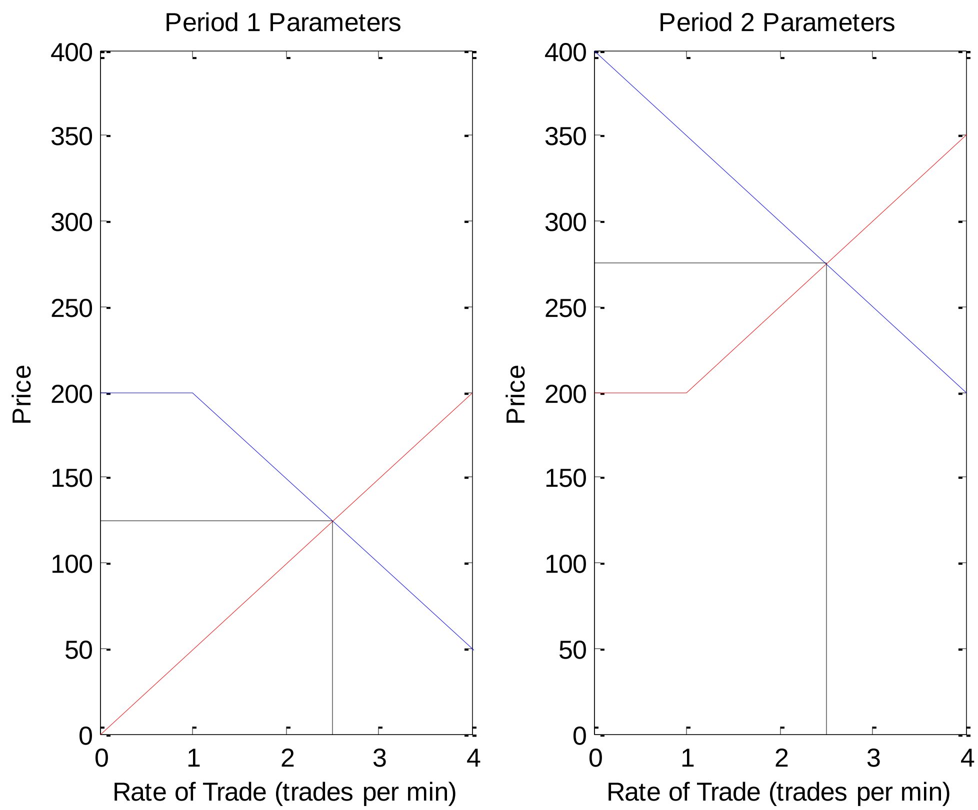
Figure 4.1: Supply and Demand Curves



Given the above parameters, the FCE prices for the first and second half of the experiment would be 100 francs and 300 francs respectively, and trade would occur at a rate of 2 trades per minute. For a more detailed explanation of the FCE price, see (Alton & Plott, Working Paper1).

Since insiders know that prices will be higher in the second half of the experiment, the problem they face is that they would like to buy cheap units at the beginning of the experiment and sell them for more money during the second half. This type of speculation shifts the demand curve to the right during the first half of the experiment, and shifts the supply curve to the right during the second half as seen below:

Figure 4.2: Speculation Between low and High Equilibria



This raises prices in the beginning of the experiment, and lowers prices during the second half of the experiment, cutting into insiders' profits. If the insiders compete so aggressively that they drive prices up to 200 francs in the first half, and down to 200 francs in the second half, they won't make any profit off their information. In this example, 200 francs is the insiders' "break-even point." In each experiment, insiders are explicitly told what the "break-even point" is for that experiment.

Another problem for informed traders is that uninformed traders may also be observing traded price levels relative to their own private incentives. These uniformed traders may try to learn about the parameters of the market from the insiders' actions and begin to speculate themselves, cutting into insiders' profits even further.

Multiple experiments were run on each date, and insiders designations were randomly shuffled between each period. Each experiment date also included a practice period, which we also report, in which there was only a single FCE price and all subjects were informed about what that price was. Subjects earned no money during the practice period.

4.3 Information Diffusion: Theory and Measurement

Experimental outcomes can be classified into four broad categories depending on the behavior of insiders and uninformed traders. Identically informed insiders can either perfectly compete or imperfectly compete, while uninformed traders can act as naïve price takers, demanding liquidity based solely on their private redemption values, or act strategically, inferring insiders information from market prices and competing with insiders to gain information rents by providing liquidity.

These experimental outcomes are described in Table 4.1 and do not necessarily conform to any specific theory of trading behavior. If uninformed individuals act solely on their private incentives, then they will never submit limit orders above their private willingness to buy or below their private willingness to sell. This means that naïve uninformed traders will be primarily liquidity demanders. Prices will be fully revealing if insiders compete perfectly, and be less than fully revealing if insiders compete imperfectly.

Table 4.1: Competing Theories of Information Diffusion

		Insiders: Perfect Competition	Insiders: Imperfect Competition
Uninformed	Naïve Price Taking	• 100% Information aggregation • Close to 100% of informational rents going to uninformed • Insiders supply most of the market's liquidity • (Holden & Subrahmanyam, 1992) (Back, Cao, & Willard, 2000)	• 50% Information aggregation • Most of informational rents gong to insiders • Insiders supply most if the market's liquidity • (Holden & Subrahmanyam, 1992) (Back, Cao, & Willard, 2000)
	Strategic Behavior	• 100% Information aggregation • Close to 100% of informational rents going to uninformed • Both insiders and uninformed supply liquidity • (Copeland & Friedman, 1991)	• >50%, <100% Information aggregation • Informational rents split between insiders and uninformed • Both insiders and uninformed supply liquidity • (Kyle, 1985)

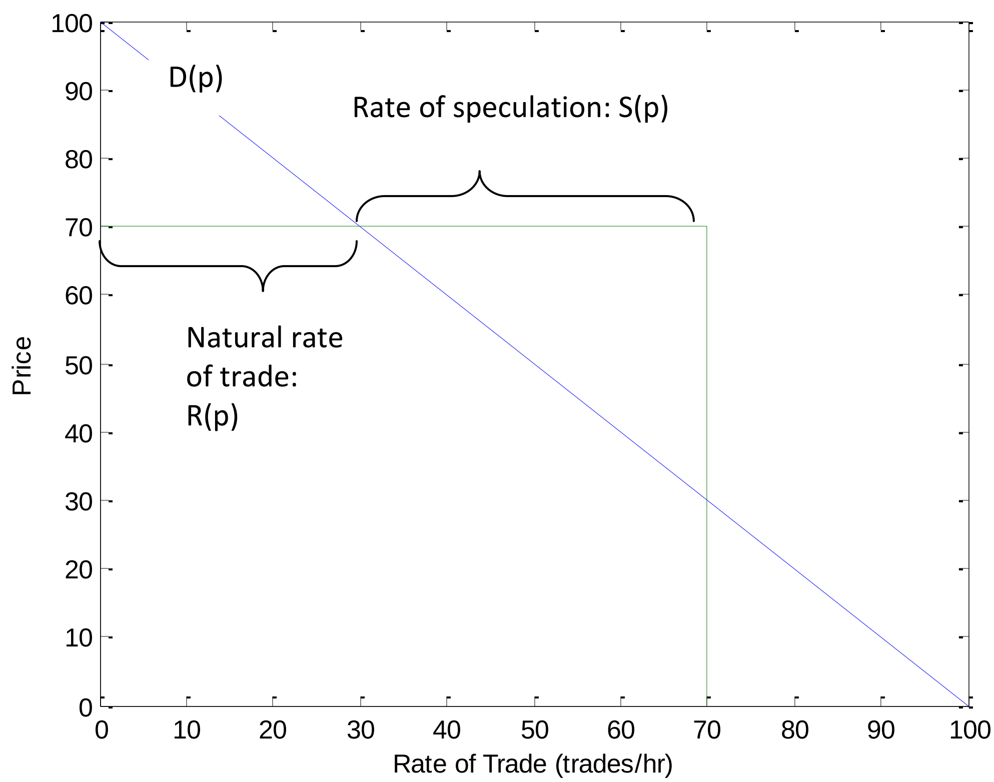
4.3.1 A Theory of Information Diffusion

In a pure common value double auction similar to (Glosten & Milgrom, 1985), information becomes reflected in prices through a process of Bayesian updating on the part of a rational market maker(s). In such an environment, the market maker continually updates prices after each trade so that the midpoint of the bid-ask spread is equal to the expected value of the asset, and uninformed agents are unable to profit off the insiders' information.

When private incentives to trade are introduced, however, trading on the part of insiders directly transmits information to uninformed traders, allowing them to profit off the information of insiders. To see this, consider the example given in Section 2. In the first half of trading, the FCE price is low relative to second half of trading, creating opportunities for insiders to profit from buying during the first period and selling during the second period.

Both insiders and uninformed traders observe both a current trading price and the rate of trade at that price, which can be compared to the natural rate of trade at the current price.

Figure 4.3: Rate of Speculation



$$\text{Let } R(P) = \begin{cases} D(p), \text{if } p > \text{FCE price} \\ S(p), \text{if } p \leq \text{FCE price} \end{cases} \qquad (4.1)$$

be the natural rate of trade for the entire market, where D and S are the demand and supply functions. Then, both informed and uninformed traders can observe:

$$S(p) = \sum_{i \in U} S_i^u\,(p) + \sum_{j \in I} S_j^I(p) \qquad (4.2)$$

Where $S_i^u(p)$ is the rate of speculation of uninformed agent i at a price of p and $S_j^I(p)$ is the rate of speculation of informed agent j at price p.

Notice that, under the assumptions that all of the speculation in the market up until a given point in time is due to insiders and that the insiders interpret their information correctly (i.e., they are on the correct side of the market), outsiders can infer the direction of the Full Information Price (FIP) based on the direction of speculation. Outsiders cannot, however, identify the individual values of $\sum_{i \in U} S_i^u\,(p)$ and $\sum_{i \in U} S_i^I\,(p)$, nor can they learn the exact location of the FIP without more information about insiders' trading strategies.

4.3.2 Measuring Information Diffusion

In each experiment, there is at least one shift in equilibrium. More aggregate surplus is available by trading at the full-information price with a higher rate of transaction than there is trading at a slower rate at each of the individual FCE prices. Since the amount of surplus available by trading at each of the individual FCE does not depend on information, we can subtract this amount from the actual level of surplus extracted during an experiment to obtain the amount of rent achieved due to information. We can also take the difference in the amount of surplus available at the full-information equilibrium and at the individual FCE's to obtain the maximum amount of informational rent that could be extracted during an experiment. Dividing these two numbers gives us a measure of informational efficiency.

$$\%\ Information\ Aggregation = \frac{Informational\ \ Rent}{Max\ Informational\ \ Rent} = \frac{(Actual\ Surplus\ - FCE\ Surplus\ )}{(Max\ Surplus\ - FCE\ Surplus\ )} \quad (4.3)$$

An alternative measure based on (Smith V. , 1962) looks at the average distance of traded prices to the full information price.

$$Average\ Distance\ to\ Full\ Information\ Price\ \frac{1}{N}\sum_{t=1}^{N}|P_t - FIP_t| \quad (4.4)$$

It should be noted that the measure of informational efficiency defined in Equation (4.3) above has little to do with the level of traded prices in the experiment. Likewise Equation (4.4) has little to do with efficiency. An experiment can have traded prices that are very different from the full information price and still have high levels of informational efficiency. This is because Equation (4.3) only measures the aggregate amount of surplus achieved, and does not depend on how that surplus is divided between buyers and sellers.

4.4 Results

The results are divided into 5 sections. In Section 4.4.1, we discuss results related to the informational efficiency, and how information surplus is distributed among insiders and non-insiders. In Section 4.4.2, we examine the strategic behavior of insider and uninformed agents in terms of the choice between market and limit orders. Section 4.4.3 examines the evolution of insiders and outsiders' inventory positions and suggests that information is transmitted from insiders to outsiders via the observable rate of trade in the market. Finally, in Section 4.4.4, we show that information is not incorporated into prices through signed order flow.

4.4.1 Informational Efficiency

Result 1: Informational efficiency in random arrival market experiments with competing insiders is high, though typically below 100%. Approximately one third of information surplus accrued to insiders.

Support: Table 4.2 computes the percentage of information aggregated in each experiment using Equation (4.1). Information aggregation in the experiments considered ranged from 42% (58% excluding experiment 080727 period 3) to virtually 100%. Also listed in Table 4.2 are the percentages of information rent accrued to all insiders and all uninformed agents. Since insiders had no private markets in these experiments it is assumed that all of their earnings from that period are attributed to information.

The results listed in Table 4.2 are consistent with imperfect competition among insiders and strategic behavior among the uninformed, since the level of information aggregation was typically less than 100% and most of the surplus due to information was actually accrued to the uninformed.

The only anomalous results come from experiment 080727 pd 3, in which aggregate insider profits were negative and the level of information aggregated was less than one half. Most of the insider losses in this experiment were accounted for by a single insider who failed to unload all of his inventory before the end of the experiment. This was likely due to the subject misunderstanding either his inside information, or the instructions for trading. As a result of this behavior, we exclude this experiment when calculating the average amount of information aggregation.

Table 4.2: Experimental Results

Date	Period	Max Surplus	FCE Surplus	Actual Surplus	Informational Rent	Informational Efficiency	Percent of information Rent Accrued to Insiders	Percent of information Rent Accrued to Non-Insiders
080611	1	4923	4923	1428	NA	NA	NA	NA
080611	2	44566	23868	35794	11926	58%	51%	49%
080611	3	67828	22618	61529	38911	86%	34%	66%
080611	4	57808	27904	54454	26550	89%	9%	91%
080611	5	98574	28881	98308	69427	100%	30%	70%
080727	1	6804	6804	5214	-1590	NA	NA	NA
080727	2	88886	33700	81020	47320	86%	25%	75%
080727	3	55987	31166	41631	10465	42%	-149%	249%
080727	4	119118	64213	111466	47253	86%	50%	50%
080727	5	56023	31179	36893	5714	23%	32%	68%
Average*						84%	33%	67%

* Average excludes 080727 pd. 3

4.4.2 Price Levels

A natural assumption given the fact that the average level of informational efficiency was about 85% is that traded prices would have remained close or equilibrated to the full information price. Another natural assumption, given the results of (Alton & Plott, Working Paper1) and (Alton & Plott, Working Paper2), is that when information diffusion is less than 100%, prices will be pulled toward the FCE price as well. We state these possibilities as Hypothesis 1 and 2:

Hypothesis 1: Traded prices will stabilize to the full information equilibrium price.

Hypothesis 2: Traded prices will be affected by both the full information price and the flow competitive equilibrium price. Prices will typically be found between the two equilibria.

Result 2: Hypothesis 1 is false. Traded prices typically did not stabilize to the full information price. Hypothesis 2 is correct. Prices were slightly more likely to be found between the full information price and the FCE price.

Support: As stated earlier, informational efficiency, as we measure it, has little to do with price levels, and the experimental results bear that out.

As support of Result 2, we refer to Figure 4.3, which plots traded price paths for all experiments along with FCE prices, the full information price, and aggregate levels of inventory. Figure 4.3 shows that prices tend not to equilibrate to a constant level.

The average distance across all experiments to the full information price, as measured by equation (4.2), was 39 francs, or about 20% of the support of the distribution of latent preferences.

Traded prices, were between the FCE and the full information price about XX% of the time, which is significantly different from 50% at the 99% confidence level, and hence we accept Hypothesis 2. This result holds regardless of whether we include experiment 080727 pd 3.

The influence of the FCE away from the full information price is likely the result of uncertainty about the full information price on the part of non-insiders. To test whether the influence of the FCE changes over time as information is transmitted from insiders to non-insiders, we include interactions between the FCE, TE, FIP and a dummy variable indicating that the trade occurred during the last period of an experiment. Surprisingly, we find that traded prices continue to be biased in the direction of the FCE price even in the last period of each experiment.

Table 4.3: Predicting Prices Based on Competing Equilibria

Variable	Coeficient
FCE	0.28***
FIP	0.75***
TE	-0.09***
FCE*Last Period	0.08**
FIP*Last Period	0.01
TE*Last Period	-0.01
Seller Initiated Dummy	-6.02**
Constant	6.13
R^2	.7774

* p<.1, ** p<.05, *** p<.01

4.4.3 Inventories

A fundamental question regarding auctions with asymmetric information has been whether markets diffuse information. That is, do non-insiders learn the information held by insiders as trading evolves.

One way to answer this question is to compare the market activities of insiders and uninformed traders in terms of inventories. Since uninformed traders, trading solely on the basis of their private incentives, have no reason other than information learned from insiders to accumulate positive or negative levels of inventory. While the inventory levels of uninformed traders may fluctuate, they have no reason to trend over time. Therefore, any trend in non-insider inventories can be attributed to information flow between insiders and outsiders.

Result 3: The inventory buildup of uninformed traders mirrors the inventory buildup of insiders.

Figures 4.4 and 4.5 show the aggregate and average levels of inventories per trader for both insiders and uninformed agents. Outsiders' inventories tend to trend with insiders. In nearly every period, uninformed traders accumulate non-zero inventory levels in the same direction as informed traders. The level of inventory per trader is typically less than the level of inventory per informed trader, but the level of inventory buildup on the part of uninformed traders does occasionally exceed that of informed subjects. This can be clearly seen in 080727 period 4 in which nearly all of the speculation during the first half of the experiment is accounted for by outsiders.

Figure 4.4: All Experiments and Inventories

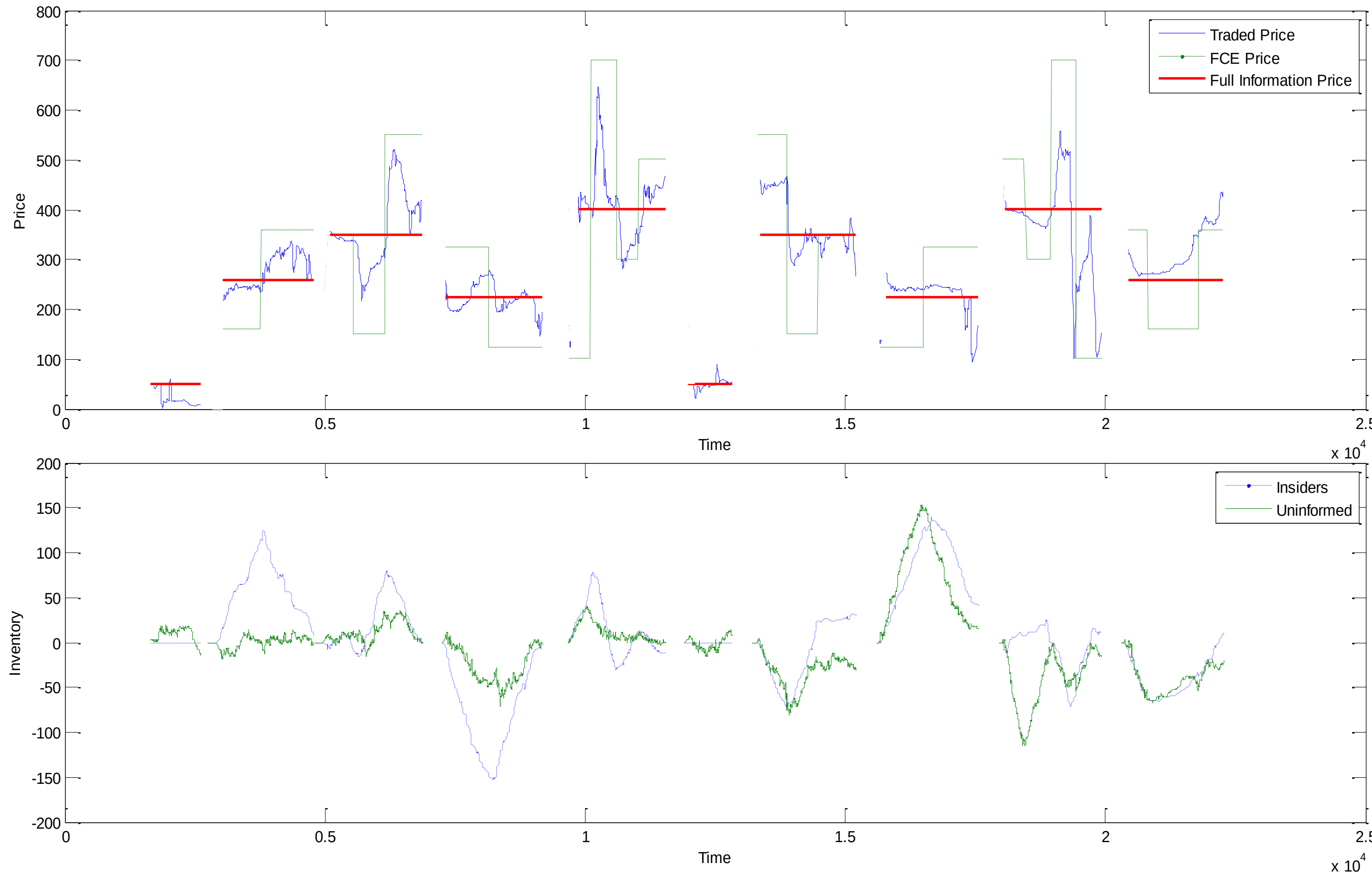
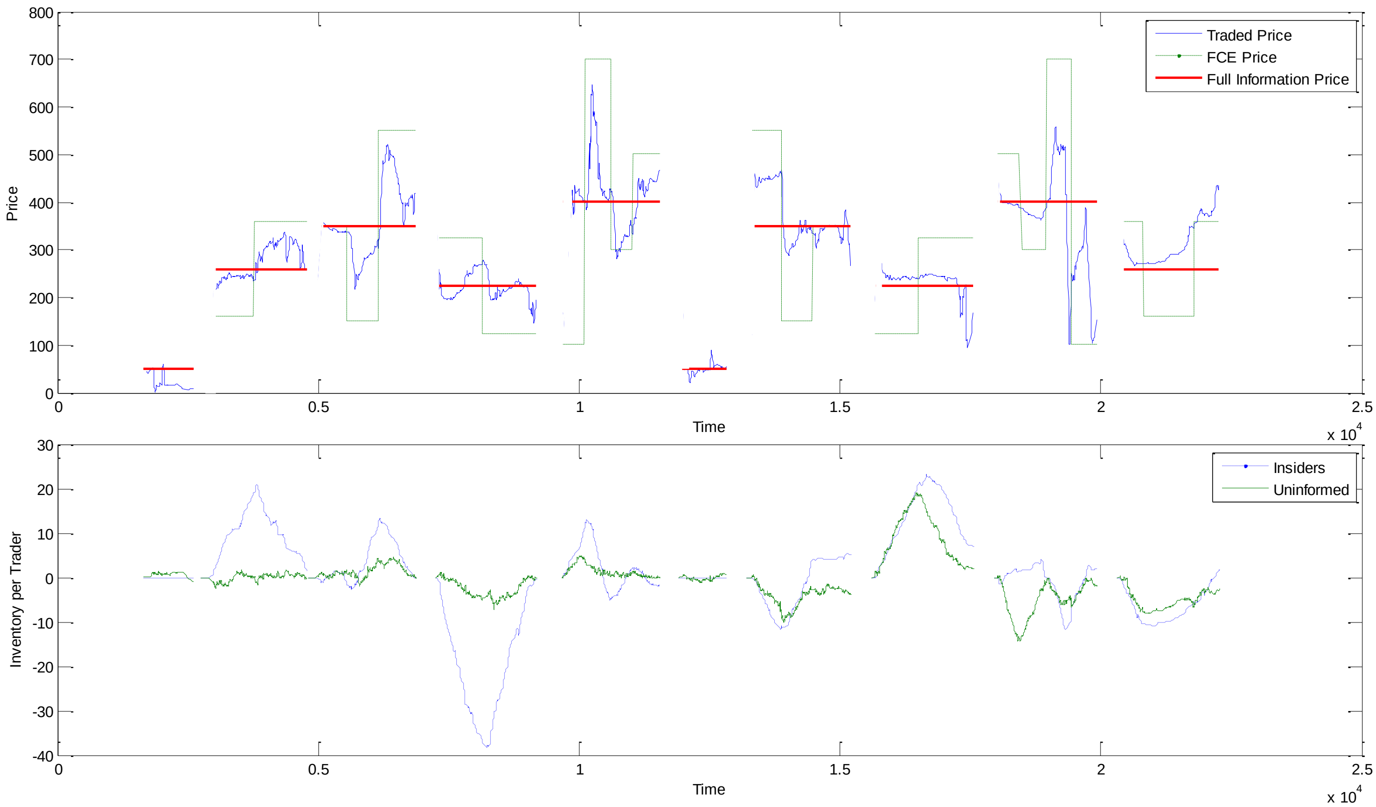


Figure 4.5: All Experiments and Inventories per Trader



In Section 4.3.1 we show how uninformed agents can infer the total signed rate of speculation in a market by comparing the rate of trade at current market prices to the "natural rate of trade," the rate at which trade would ordinarily proceed, at that price, in the absence of insiders.

To test this theory, we divide each experiment into thirty-second intervals. For each interval, we measure the average change in inventory per trader for both insiders and uninformed traders and the FIP and FCE price at the beginning of the interval. We then regress the rate of inventory accumulation per thirty seconds on a single lag of inventory accumulation rates, as well as dummy variables indicating whether the FCE price is less than or greater than the FIP at the beginning of the interval.

Hypothesis 3: The inventory accumulation rate of non-insiders will depend on the lagged total rate of inventory accumulation.

Hypothesis 4: Insiders inventory accumulation rate will be driven by the location of FCE relative to the FIP.

Hypothesis 5: Competition for information rents will also affect insiders' inventory accumulation decisions, reflected in a significantly positive slope coefficient on the lagged total rate of inventory accumulation.

Result 4: Uninformed traders use the observed rate of trade to speculate on the direction of the Full Information Price, but never learn either the identities of the insiders or the true location of the Full Information Price.

Table 4.4 summarizes the results for uninformed traders. A t-test of the hypothesis that the coefficients on lagged rate of inventory accumulation per uninformed trader and lagged rate of inventory accumulation per informed trader are equal fails to reject the null hypothesis at the 90% confidence level. This means that while uninformed traders are about to speculate on the direction of the FIP based on the total rate of speculation in the market, they are unable to identify exactly how much speculation is due to insiders and how much is due to other uninformed subjects.

Interestingly, conditional on the total rate of speculation, outsiders' inventory accumulation does not depend at all on the relative location of the FCE to the FIP. This means that despite the ability of uninformed agents to profit off the observed rate of speculation, they never actually learn the true FIP. An implication of this is that these markets are likely to be subject to informational mirages and bubbles (see (Camerer & Weigelt, 1991), (Oechssler, Schmidt, & Schnedler, 2007)). Such a situation can occur in which uninformed traders rationally respond to market information which might possibly contain information about the state of the world, but which in actuality does not.

Table 4.4: Inventory Accumulation Rate of Uninformed Traders

Variable	Coefficient
Lagged Rate of Inventory Accumulation per Uninformed Trader	0.08**
Lagged Rate of Inventory Accumulation per Informed Trader	0.10**
FCE<FIP Dummy	0.18
FCE>FIP Dummy	-0.14
Constant	-0.03
R^2	0.13

* p<.1, ** p<.05, *** p<.01

Result 5: Hypothesis 4 is correct. The aggregate rate of insiders depends on location of the FCE price relative to the FIP. When the FCE is below the FIP, insider have a positive rate of inventory accumulation. When it is above the FIP, insiders have a negative, rate of inventory accumulation.

Result 6: Insiders are also affected by competition, accelerating their rate of inventory accumulation in direct response to past rates of accumulation.

The results for insiders are listed in Table 4.5. The effect of competition from both insiders and uninformed traders is much higher for insiders than it is for outsiders. For every ten units accumulated per thirty second interval, informed traders tend to increase their rate of speculation as a whole by about 3 to 6 additional units in the next thirty second interval.

Over all experiments, insiders tended to over accumulate inventory during periods of low FCE prices and under sell inventory during periods of high FCE. This is reflected in the slope coefficients FCE<FIP Dummy and FCE>FIP Dummy not summing to zero, although both estimates are in the direction predicted by theory.

Table 4.5: Inventory Accumulation Rate of Uniformed Traders

Variable	**Coefficient**
Lagged Rate of Inventory Accumulation per Uninformed Trader	0.30***
Lagged Rate of Inventory Accumulation per Informed Trader	0.58***
FCE<FIP Dummy	0.21**
FCE>FIP Dummy	-0.11*
Constant	-0.01
R^2	0.57

* p<.1, ** p<.05, *** p<.01

4.4.4 The Effects of Order Flow on Price Changes

In the common value environment studied by (Glosten & Milgrom, 1985), asymmetric information held by insiders is gradually incorporated into prices via signed order flow. By convention, trades initiated by market orders to buy are signed positively, and trades initiated by market orders to sell are signed negatively.

Market orders play a special informational role in Glosten and Milgrom's theory because of the assumption that informed traders transact only through market orders. This assumption is based on the idea that informed traders attempt to hold off revealing their information to the market. When traded prices in a double auction increase (decrease), it is either because of an increased (decreased) rate of buy (sell) market orders eroding asks (bids) in the sell (buy) order book, or because of an increase (decrease) in the level of limit prices at which market orders transact. By submitting a higher bid or lower ask than the current market prices, an insider risks revealing the direction of his or her information prior to making a transaction. Placing market orders, on the other hand, also reveals a small amount of insiders' information to the market, but does so after the insider has already transacted. Exactly why insiders have this preference is not fully explained by the Glosten and Milgrom model and is hence left as an assumption rather than a consequence of utility maximizing behavior.

Alton (Chapter 1) shows that the informational content of trades can be estimated by looking at runs in trade initiation. When we apply the same methodology to our experimental data, we discover that, while the direction of trade initiation does appear to impact prices, the actual amount traded in each run, paradoxically, does not affect prices.

Result 7: Asymmetric information in Random Arrival Markets is not transmitted through signed order flow. The direction of order flow however, does impact prices.

Table 4.6: Effect of Signed Run Size on Traded Prices

Variable	Coefficient
Positive Order Flow Dummy	31.96***
Size of Trade Run	0.24
Constant	-16.06***
R^2	0.14

* p<.1, ** p<.05, *** p<.01

According to the results presented in Table 4.6, positive order flow (buy market orders) tend to increase traded prices by approximately 32 Francs per run and negative order flow tends to decrease prices by about 16 Francs per run. The fact that prices tend to increase more on a positive run than they decrease on a negative run, is due to a combination of parameter choices (tending to shift FCE prices upward over the course of an experiment) as well as mistakes made by insiders (such as in 080727 pd. 3, in which insiders accumulated too much inventory during the first half of the experiment and failed to unload all of it by the end of the experiment). The size of the signed order flow, on the other hand, which should be the only significant explanatory variable, is not significantly different from zero. While this indicated that prices generally move in the direction predicted by theory, it also indicated a general deficiency in the theory.

Figure 4.6: Scatter Plot of Price Changes Vs Size of Run Size

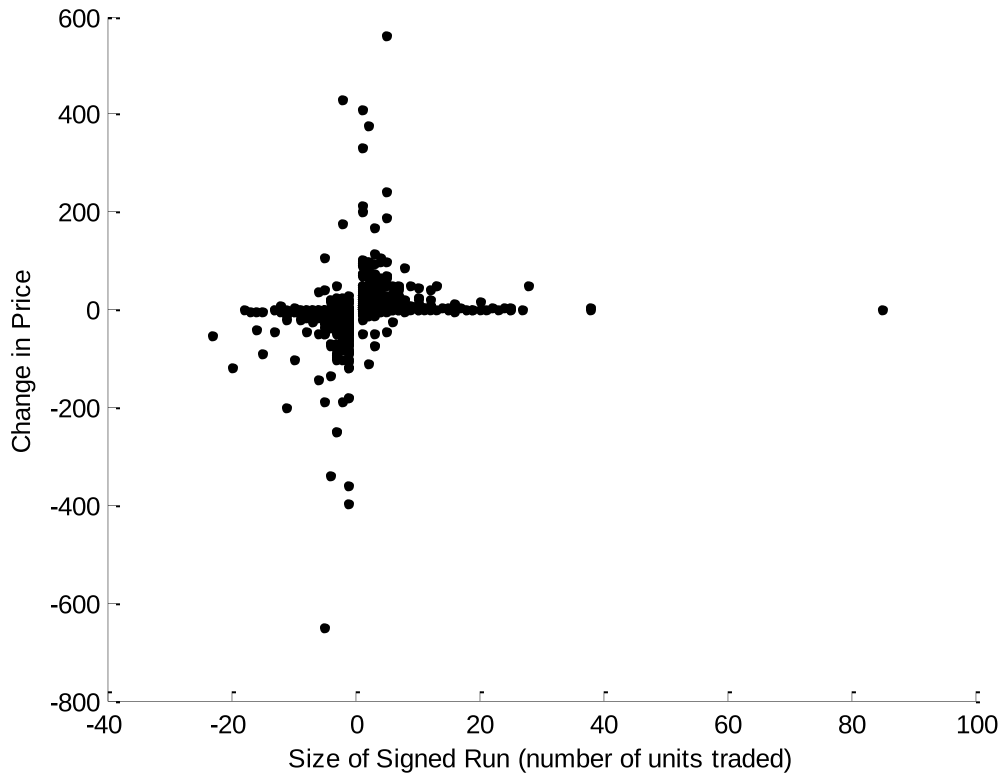


Figure 4.6 shows a scatter plot of the raw price change data in which it can be clearly seen that buy market orders tend to increase prices and market sell orders tend to decrease prices, but there is no linear relationship between the size of a run in trade initiation and its effect. A part of this result may be due to insiders' choice of whether to transact via market or limit orders.

A common assumption regarding informed traders is that informed traders trade primarily through market orders. This is due either to the mathematical complexity involved in creating theories in which insiders submit both limit and market orders, or because market orders are believed to carry less information than limit orders and insiders never want to reveal their information to the market. Whatever the reason, we state this as Hypothesis 6, and test it by comparing the proportion of limit orders sent by insiders to the proportion of limit orders sent by non-insiders.

Hypothesis 6: Informed subjects will always submit market orders.

Result 8: We reject hypothesis 6. Informed subjects submitted both market and limit orders in the same proportion as uninformed traders.

There were no significant differences between insiders and uninformed agents in terms of the proportion of limit and market orders that both types of agents submitted. Both uniformed and informed trades submitted about 60% of their orders in the form of limit orders. This result can be seen in Table 4.7 below, which lists the number of limit and market orders submitted by insiders and uninformed traders.

Table 4.7: Market And Limit Order Submission

	Number of Orders	Submitted by Insiders	Submitted by Uninformed
Limit Bids	2693	251	2444
Limit Asks	2196	245	1951
Market Buy	2063	132	1931
Market Sell	1497	160	1337

Excluded 080727 pd 3

Result 9 helps to explain why price movement does not seem to be directly related to signed order flow. Such a result may also explain why the measured effect of asymmetric information in the Australian Stock Market in Chapter One appears to be so small. If informed traders attempt to hide their identities in electronic limit order markets by placing both market and limit orders in the same proportion as the rest of the market, such behavior can attenuate the measurements of the effect of asymmetric information toward zero.

4.5. Conclusions

Prices, efficiencies and inventory levels indicate that trading in random arrival markets with competing insiders is characterized by incomplete information incorporation into prices and incomplete diffusion of information form insiders to uninformed agents. While high, levels of efficiency are typically well below 100%, and prices do not converge to the full information price as predicted by (Back, Cao, & Willard, 2000) and (Holden & Subrahmanyam, 1992).

The results of the experiments presented here suggest that partial information diffusion in random arrival markets can be achieved through uninformed subjects observing the price and rate of trade in a market and comparing it to the natural rate of trade. While such behavior can allow uninformed traders to successfully speculate in the same direction as insiders, outsiders never fully learn the location of the Full Information Price.

This chapter also suggests a possible explanation for why measurements of the effect of asymmetric information on asset prices may be hard to detect in electronic limit order markets. When insiders transact through both limit and market orders, which are oppositely signed when determining signed order flow, the measured effects of signed order flow are attenuated toward zero.

Chapter 5 Bibliography

Ahn, H.-J., & Cheung, Y. (1999). Intraday Patterns of the Spread and Depth in a Market with Market Makers: the Stock Exchange of Hong Kong. *Pacific-Basin Finance Journal , 7*.

Ahn, H.-J., Bae, K.-H., & Chan, K. (2001). Limit Orders, Depth and Volatility: Evidence from the Stock Exchange of Hong Kong. *Journal of Finance , 56*.

Aliprantis, R., & Plott, C. (1992). Competitive Equilibria in Overlapping Generations Experiments. *Econometric Theory , 2*, 389-426.

Alton, M., & Plott, C. (Working Paper2). Price Dynamics of Random Arrival Markets.

Alton, M., & Plott, C. (Working Paper1). Principles of Continuous Price Determination in an Experimental Environment with Flows of Random Arrivals and Departures.

Amihud, Y., & Mendelson, H. (1980). Dealership Market: Market-Making with Inventory. *Journal of Financial Economics , 8*, 31-53.

Asparouhova, E., Bossaerts, P., & Plott, C. (2003). Excess Demand and Equilibration in Multi-Security Financial Markets: The Empirical Evidence. *Journal of Financial Markets , 6*, 1-21.

Back, K., Cao, H., & Willard, G. (2000). Imperfect Competition Among Informed Traders. *The Journal of Finance , 55* (5), 2117-2155.

Bias, B., Hillion, P., & Spatt, C. (1995). An Empirical Analysis of the Limit Order Book and the Order Flow in the Paris Bourse. *Journal of Finance , 50* (5).

Blooerslev, T., & Domowitz, I. (1993). Some Effects of Restricting the Electronic Order Book in an Automated Trade Execution System. In D. Friedman, & J. Rust, *The Double Auction Market: Theory and Evidence* (pp. 221-252). Redwood City: Addison-Wesley.

Bollerslev, T., & Melvin, M. (1994). Bid-Ask Spreads and Volatility in the Foreign Exchange Market: An Empirical Analysis. *Journal of International Economics , 36*.

Bortoli, L., Frino, A., Jarnecic, E., & Johnstone, D. (2006). Limit Order Book Transparency, Execution Risk and Market Liquidity. *Working Paper* .

Brewer, P., Jiang, M., & Plott, C. (2003). On the Behavioral Foundations of the Law of Supply and Demand: Human Convergence and Robot Randomness. *Experimental Economics , 5*, 179-208.

Camerer, C., & Weigelt, K. (1991). Information Mirages in Experimental Asset Markets. *Journal of Business , 64*.

Cason, T., & Friedman, D. (1993). Empirical Analysis of Price Formation in Double Auction Markets. In D. Friedman, & J. Rust, *The Double Auction Market: Institutions, Theory and Evidence* (pp. 253-284). Redwood City, CA: Addison-Wesley.

Chamberlin, E. (1948). An Experimental Imperfect Market. *Journal of Political Economy* , 95-108.

Chan, Y.-C. (2005). Price Movement Effects on the State of the Electronic Limit-Order Book. *The Financial Review , 40* (2).

Choi, J., Salandro, D., & Shastri, K. (1988). On the Estimation of Bid-Ask Spreads: Theory and Evidence. *The Journal of Financial and Quantitative Anaylsis , 23* (2).

Cliff, D., & Preist, C. (1998). *Days Without End: On the Stability of Experimental Single Period Continous Double Auction Markets.* Hewlett-Packard Laboratories.

Copeland, T., & Friedman, D. (1991). Partial Revelation of Information in Experimental Asset Markets. *The Journal of Finance , 46* (1).

Copeland, T., & Galai, D. (1983, Dec.). Information Effects on the Bid-Ask Spread. *Journal of Finance* .

Danielson, & Payne. (2001). Liquidity Determination in an Order Driven Market. *Working Paper* .

Easley, D., & Ledyard, J. (1993). Theories of Price Formation and Exchange in Double Oral Auctions. In D. Friedman, & J. Rust (Eds.), *The Double Auction Market Institutions, Theories, and Evidence* (pp. 63-97). Addison-Wesley.

Easley, D., & O'Hara, M. (1987). Price, Trade Size and Information in Securities Markets. *Journal of Financial Economics , 19*.

Forsythe, R., & Lundholm, R. (1990). Information Aggregation in an Experimental Market. *Econometrica , 58* (2).

Forsythe, R., Palfrey, T., & Plott, C. (1982). Asset Valuation in an Experimental Market. *Econometrica , 50*, 537-567.

Foucault, T. (1999). Order Flow Composition and Trading Costs in a Dynamic Limit Order Market. *Journal of Financial Markets , 2*.

Foucault, T., Kadan, O., & Kandel, E. (2003). The Limit Order Book and a Market for Liquidity. *Working Paper* .

Friedman, D. (1991). A Simple Testable Model of Double Auction Markets. *Journal of Economic Behavior and Organizations , 16*, 47-70.

Garman, M. (1976). Market Microstructure. *Journal of Financial Economics , 3* (3), 257-275.

George, T., Kaul, G., & Nimalendran, M. Estimation of the Bid-Ask Spread and It's Components: A New Approach. *The Review of Financial Studies , 4*, 1991.

Glosten, L. (1987). Components of the Bid-Ask Spread and the Statistical Properties of Transaction Prices. *The Journal of Finance , 42*.

Glosten, L., & Harris, L. (1988). Estimating Components of the Bid/Ask Spread. *Journal of Financial Economics , 19*.

Glosten, L., & Milgrom, P. (1985). Bid, Ask and Transaction Prices in a Specialist Market with Heterogeneously Informed Traders. *Journal of Financial Economics , 14*.

Gode, D., & Sunder, S. (1993). Alocative Efficiency of Markets with Zero Intelligence Traders: Markets as a Partial Substitute for Rationality. *The Journal of Political Economy , 101*, 119-137.

Goettler, R., Parlou, C., & Uajan, U. (2005). Equilibrium in a Dynamic Limit Order Market. *Journal of Finance , 60* (5), 2149-2192.

Harris, L. (1990). Estimation of Stock Price Variance and Serial Covariances from Discrete Observations. *The Journal of Financial and Quantitative Analysis , 25*.

Hasbrouck, J., & Sofianos, G. (1993). The Trades of Market Makers: An Empirical Analysis of NYSE Specialists. *The Journal od Finance , 48*.

Hirota, M., Hsu, M., Plott, C., & Rogers, B. (2005). Divergence of Closed Cycles and Convergence in Scarf Environments: Experiments in the Dynamics of General Equilibrium Systems. *Caltech Working Papers* .

Ho, T., & Stoll, H. (1981). Optimal Dealer Pricing Under Transaction and Return Uncertainty. *Journal of Financial Economics , 9*.

Holden, C., & Subrahmanyam, A. (1992). Long Lived Private Information and Imperfect Competition. *Journal of Finance , 47*, 247-270.

Huang, R., & Stoll, H. (1997). The Components of the Bid-Ask Spread: A General Approach. *Review of Financial Studies , 10*.

Jamison, J., & Plott, C. (1997). Costly Offers and the Equilibrium Properties of the Multiple UNit Double Auction Under Conditions of Unpredictable Shifts of Demand and Supply. *Journal of Economic Behavior and Organization , 31* (4), 591-612.

Kagel, J. (2004). Double Auction Markets with Stochastic Supply and Demand Schedules: Call Markets and Continuous Auction Trading Mechanisms. In S. Hack (Ed.), *Advances in Understanding Strategic Behavior: Essays in Honor of Werner Guth.* Palgrave.

Kyle, A. (1985). Continuous Auctions and Insider Trading. *Econometrica , 53*, 1315-1335.

Lei, V., Noussair, C., & Plott, C. (2001). Nonspeculative Bubbles in Experimental Asset Markets: Lack of Common Knowledge of Rationality vs. Actual Irrationality. *Econometrica , 69* (4).

Madhavan, A., & Smidt, S. (1993). An Analysis of Changes in Specialist Inventories and Quotations. *The Journal of Finance , 48*.

Marimon, R., & Sunder, S. (1993). Indeterminacy of Equilibria in a Hyperinflationary World: Experimental Evidence. *Econometrica , 61* (5), 1073-1108.

Miller, R., Plott, C., & Smith, V. (1977). Intertemporal Competetive Equilibria: An Empirical Study of Speculation. *Quarrterly Journal of Economics , 91*, 599-624.

Millner, E., Pratt, M., & Reilly, R. (1990). Contestability in Real-Time Experimental Flow Markets. *Rand Journal of Economics , 21* (4), 584-499.

Oechssler, J., Schmidt, C., & Schnedler, W. (2007, April). Asset Bubbles without Dividends - An Experiment. *Working Paper* .

O'Hara, M. (1995). *Market Microstructure Theory.* Blackwell Publishing.

O'Hara, M., & Oldfield, G. (1986). The Microeconomics of Market Making. *Journal of Financial and Quantitative Analysis , 21*.

Parlour, C. (1998). Price Dynamics in Limit Order Markets. *Review of Financial Studies , 11*, 789-816.

Parlour, C. (1998). Price Dynamics in Limit Order Markets. *Review of Financial Studies , 11* (4).

Parlour, C., & Seppi, D. (Forthcomming). Limit Order Markets: A Survey. In A. Boot, & A. Thankor (Eds.), *Handbook of Financial Intermediation & Banking.*

Peng, L., & Plott, C. (1998). General Equilibrium, Markets, Macroeconomics and Money in a Laboratory Experimental Environment. *Economic Theory , 12* (1), 21-75.

Plott, C., & Gray, P. (1990). The Multiple Unit Double Auction. *Journal of Economic Behavior and Organization , 13*, 245-258.

Plott, C., & Smith, V. (1978). An Experimental Examination of Two Exchange Institutions. *The Review of Economic Studies , 45* (1), 133-153.

Roll, R. (1984). A Simple Implicit Measure of the Effective Bid-Ask Spread in an Efficient Market. *The Journal of Finance , 39*.

Smith, V. (1962). An Experimental Study of Competetive Market Behavior. *Jouranl of Political Economy , 70* (2), 111-137.

Smith, V. (1965). Experimental Auction Markets and the Walrasian Hypothesis. *Journal of Political Economy , 73*, 387-393.

Smith, V. (1976). Induced Value Theory. *The American Economic Review , 66* (2).

Smith, V., Suchanek, G., & Williams, A. (1988). Bubbles, Crashes and Endogenous Expectations in Experimental Spot Asset Markets. *Econometrica , 56*, 1119-1151.

Stoll, H. (1989). Inferring Components of the Bid-Ask Spread: Theory and Empirical Tests. *The Journal of Finance , 44*.

Warren, E. (1975). *A Dynamic, Stochastic Model of Stock Market Adjustment.* Purdue University.

Wilson, R. (1987). On Equilibria of Bid-Ask Markets. In G. Feiwel (Ed.), *Arrow and the Ascent of Modern Economic Theory* (pp. 375-414). U.K.: MacMillan.

Chapter 6 Appendices

6.1 Appendices from Chapter1

6.1.1 Predicting the Size of Trade Initiation Runs

IVC

Obs	1636
R-squared	0.1234
Adj R-squared	0.1037

Dep. Var: Size of Run	Coef.	Std. Error	t	P>|t|	[95% Conf. Interval]	
Last trade at Bid Price	0.033	0.112	0.29	0.77	-0.186	0.252
Lag(Quantity traded at Bid)	0.033	0.036	0.93	0.35	-0.037	0.103
Lag2(Quantity traded at Bid)	0.262	0.036	7.29	0.00	0.191	0.332
Lag3(Quantity traded at Bid)	0.049	0.037	1.31	0.19	-0.024	0.121
Lag3(Quantity traded at Bid)	0.124	0.037	3.36	0.00	0.052	0.197
Lag4(Quantity traded at Bid)	0.116	0.036	3.21	0.00	0.045	0.187
Lag5(Quantity traded at Bid)	0.019	0.036	0.54	0.59	-0.052	0.091
lqatask						
Quantity traded at Ask	0.014	0.036	0.40	0.69	-0.057	0.086
Lag(Quantity traded at Ask)	0.127	0.036	3.52	0.00	0.056	0.197
Lag2(Quantity traded at Ask)	0.035	0.036	0.97	0.33	-0.036	0.107
Lag3(Quantity traded at Ask)	0.127	0.036	3.52	0.00	0.056	0.198
Lag4(Quantity traded at Ask)	-0.003	0.036	-0.07	0.94	-0.074	0.069
Lag5(Quantity traded at Ask)	0.030	0.036	0.84	0.40	-0.041	0.102
Lag6(Quantity traded at Ask)	0.030	0.036	0.85	0.40	-0.039	0.100
Time (in sec from Open)	-0.187	0.097	-1.93	0.05	-0.376	0.003
Time^2 (in sec from Open)	-0.127	0.154	-0.83	0.41	-0.430	0.175
Time^3 (in sec from Open)	0.158	0.074	2.14	0.03	0.013	0.303
Time^4 (in sec from Open)	0.085	0.072	1.18	0.24	-0.056	0.225
Ttues Dummy	-0.064	0.096	-0.67	0.51	-0.251	0.124
Wed Dummy	-0.063	0.096	-0.66	0.51	-0.252	0.126
Thurs Dummy	0.185	0.101	1.82	0.07	-0.014	0.384
Fri Dummy	0.022	0.103	0.21	0.83	-0.180	0.224
First Trading Day of Month	-0.032	0.149	-0.22	0.83	-0.324	0.260
Last Trading Day of Month	0.235	0.183	1.29	0.20	-0.124	0.593
Lag(Change in Bid Price)	-0.405	3.670	-0.11	0.91	-7.604	6.794
Lag2(Change in Bid Price)	2.116	4.300	0.49	0.62	-6.318	10.550
Lag3(Change in Bid Price)	1.826	4.485	0.41	0.68	-6.972	10.623
Lag4(Change in Bid Price)	-0.250	4.486	-0.06	0.96	-9.048	8.549
Lag5(Change in Bid Price)	-0.784	4.307	-0.18	0.86	-9.231	7.663
Lag6(Change in Bid Price)	-1.379	3.682	-0.38	0.71	-8.601	5.842
dbestask						
Lag(Change in Ask Price)	0.581	3.664	0.16	0.87	-6.607	7.768
Lag2(Change in Ask Price)	-0.507	4.256	-0.12	0.91	-8.854	7.840
Lag3(Change in Ask Price)	-2.054	4.419	-0.47	0.64	-10.722	6.614
Lag4(Change in Ask Price)	1.848	4.415	0.42	0.68	-6.812	10.509
Lag5(Change in Ask Price)	2.528	4.243	0.60	0.55	-5.795	10.851
Lag6(Change in Ask Price)	3.421	3.634	0.94	0.35	-3.706	10.548
Constant	0.003	0.111	0.03	0.98	-0.215	0.222

AWC

Obs	14373
R-squared	0.0294
Adj R-squared	1.2314

Dep. Var: Size of Run	Coef.	Std. Error	t	P>|t|	[95% Conf. Interval]	
Last trade at Bid Price	-0.043	0.047	-0.92	0.36	-0.135	0.049
Lag(Quantity traded at Bid)	0.018	0.012	1.46	0.14	-0.006	0.042
Lag2(Quantity traded at Bid)	0.093	0.012	7.66	0.00	0.069	0.117
Lag3(Quantity traded at Bid)	0.030	0.012	2.47	0.01	0.006	0.054
Lag3(Quantity traded at Bid)	0.043	0.012	3.56	0.00	0.020	0.067
Lag4(Quantity traded at Bid)	0.003	0.012	0.21	0.83	-0.021	0.026
Lag5(Quantity traded at Bid)	0.051	0.012	4.21	0.00	0.027	0.075
lqatask						
Quantity traded at Ask	0.038	0.012	3.15	0.00	0.014	0.061
Lag(Quantity traded at Ask)	0.082	0.012	6.79	0.00	0.058	0.105
Lag2(Quantity traded at Ask)	0.031	0.012	2.55	0.01	0.007	0.054
Lag3(Quantity traded at Ask)	0.079	0.012	6.56	0.00	0.055	0.102
Lag4(Quantity traded at Ask)	-0.008	0.012	-0.66	0.51	-0.032	0.016
Lag5(Quantity traded at Ask)	0.076	0.012	6.37	0.00	0.053	0.100
Lag6(Quantity traded at Ask)	0.047	0.012	3.95	0.00	0.024	0.070
Time (in sec from Open)	-0.059	0.031	-1.89	0.06	-0.120	0.002
Time^2 (in sec from Open)	0.139	0.058	2.39	0.02	0.025	0.253
Time^3 (in sec from Open)	0.063	0.021	3.09	0.00	0.023	0.104
Time^4 (in sec from Open)	-0.071	0.027	-2.61	0.01	-0.125	-0.018
Ttues Dummy	0.080	0.034	2.39	0.02	0.014	0.146
Wed Dummy	-0.019	0.032	-0.60	0.55	-0.082	0.043
Thurs Dummy	0.059	0.033	1.78	0.08	-0.006	0.124
Fri Dummy	0.040	0.033	1.20	0.23	-0.025	0.105
First Trading Day of Month	-0.021	0.053	-0.39	0.69	-0.126	0.084
Last Trading Day of Month	0.266	0.062	4.29	0.00	0.145	0.388
Lag(Change in Bid Price)	3.013	2.579	1.17	0.24	-2.043	8.068
Lag2(Change in Bid Price)	4.549	3.100	1.47	0.14	-1.527	10.624
Lag3(Change in Bid Price)	3.327	3.216	1.04	0.30	-2.976	9.630
Lag4(Change in Bid Price)	1.994	3.211	0.62	0.54	-4.300	8.289
Lag5(Change in Bid Price)	1.999	3.098	0.65	0.52	-4.074	8.072
Lag6(Change in Bid Price)	-0.972	2.581	-0.38	0.71	-6.032	4.088
dbestask						
Lag(Change in Ask Price)	-3.016	2.701	-1.12	0.26	-8.311	2.279
Lag2(Change in Ask Price)	-3.682	3.199	-1.15	0.25	-9.952	2.588
Lag3(Change in Ask Price)	-3.612	3.312	-1.09	0.28	-10.103	2.880
Lag4(Change in Ask Price)	-2.034	3.307	-0.62	0.54	-8.516	4.447
Lag5(Change in Ask Price)	-1.322	3.178	-0.42	0.68	-7.551	4.907
Lag6(Change in Ask Price)	2.799	2.669	1.05	0.29	-2.433	8.032
Constant	-0.057	0.040	-1.41	0.16	-0.135	0.022

BBG

Obs	5496
R-squared	0.0538
Adj R-squared	0.0475

Dep. Var: Size of Run	**Coef.**	**Std. Error**	**t**	**P>|t|**	**[95% Conf. Interval]**	
Last trade at Bid Price	-0.197	0.067	-2.91	0.00	-0.329	-0.064
Lag(Quantity traded at Bid)	0.069	0.020	3.48	0.00	0.030	0.107
Lag2(Quantity traded at Bid)	0.129	0.020	6.51	0.00	0.090	0.168
Lag3(Quantity traded at Bid)	0.051	0.020	2.56	0.01	0.012	0.090
Lag3(Quantity traded at Bid)	-0.001	0.020	-0.07	0.94	-0.041	0.038
Lag4(Quantity traded at Bid)	-0.005	0.020	-0.26	0.80	-0.044	0.034
Lag5(Quantity traded at Bid)	0.051	0.020	2.56	0.01	0.012	0.089
lqatask						
Quantity traded at Ask	0.051	0.020	2.58	0.01	0.012	0.090
Lag(Quantity traded at Ask)	0.081	0.020	4.05	0.00	0.042	0.120
Lag2(Quantity traded at Ask)	0.065	0.020	3.24	0.00	0.026	0.104
Lag3(Quantity traded at Ask)	0.128	0.020	6.46	0.00	0.089	0.167
Lag4(Quantity traded at Ask)	0.014	0.020	0.71	0.48	-0.025	0.053
Lag5(Quantity traded at Ask)	0.056	0.020	2.83	0.01	0.017	0.095
Lag6(Quantity traded at Ask)	0.003	0.019	0.14	0.89	-0.035	0.040
Time (in sec from Open)	0.061	0.048	1.28	0.20	-0.033	0.156
Time^2 (in sec from Open)	0.148	0.088	1.68	0.09	-0.025	0.321
Time^3 (in sec from Open)	-0.002	0.033	-0.06	0.95	-0.066	0.062
Time^4 (in sec from Open)	-0.048	0.040	-1.19	0.24	-0.127	0.031
Ttues Dummy	-0.033	0.053	-0.62	0.54	-0.136	0.070
Wed Dummy	0.083	0.053	1.57	0.12	-0.020	0.186
Thurs Dummy	0.031	0.057	0.55	0.59	-0.081	0.143
Fri Dummy	-0.052	0.054	-0.97	0.33	-0.158	0.054
First Trading Day of Month	0.183	0.080	2.29	0.02	0.027	0.339
Last Trading Day of Month	-0.282	0.111	-2.55	0.01	-0.499	-0.065
Lag(Change in Bid Price)	-1.152	0.983	-1.17	0.24	-3.080	0.776
Lag2(Change in Bid Price)	0.856	1.205	0.71	0.48	-1.506	3.218
Lag3(Change in Bid Price)	-0.811	1.262	-0.64	0.52	-3.285	1.662
Lag4(Change in Bid Price)	0.561	1.262	0.44	0.66	-1.913	3.035
Lag5(Change in Bid Price)	0.758	1.207	0.63	0.53	-1.608	3.125
Lag6(Change in Bid Price)	1.109	0.985	1.13	0.26	-0.823	3.041
dbestask						
Lag(Change in Ask Price)	0.472	1.091	0.43	0.67	-1.667	2.611
Lag2(Change in Ask Price)	-0.409	1.285	-0.32	0.75	-2.928	2.111
Lag3(Change in Ask Price)	0.624	1.336	0.47	0.64	-1.996	3.243
Lag4(Change in Ask Price)	-0.649	1.327	-0.49	0.63	-3.251	1.953
Lag5(Change in Ask Price)	-1.681	1.268	-1.33	0.19	-4.166	0.804
Lag6(Change in Ask Price)	-1.181	1.064	-1.11	0.27	-3.267	0.904
Constant	0.014	0.064	0.22	0.82	-0.112	0.141

GWT

Obs	1562
R-squared	0.0602
Adj R-squared	0.038

Dep. Var: Size of Run	Coef.	Std. Error	t	P>|t|	[95% Conf. Interval]	
Last trade at Bid Price	-0.135	0.135	-1.00	0.32	-0.399	0.129
Lag(Quantity traded at Bid)	0.063	0.037	1.70	0.09	-0.010	0.136
Lag2(Quantity traded at Bid)	0.129	0.037	3.46	0.00	0.056	0.202
Lag3(Quantity traded at Bid)	-0.060	0.037	-1.61	0.11	-0.133	0.013
Lag3(Quantity traded at Bid)	0.098	0.037	2.61	0.01	0.024	0.171
Lag4(Quantity traded at Bid)	0.050	0.037	1.34	0.18	-0.023	0.124
Lag5(Quantity traded at Bid)	0.066	0.037	1.76	0.08	-0.008	0.139
lqatask						
Quantity traded at Ask	-0.036	0.036	-0.98	0.33	-0.107	0.036
Lag(Quantity traded at Ask)	0.132	0.036	3.64	0.00	0.061	0.203
Lag2(Quantity traded at Ask)	0.058	0.037	1.59	0.11	-0.014	0.130
Lag3(Quantity traded at Ask)	0.051	0.037	1.41	0.16	-0.020	0.123
Lag4(Quantity traded at Ask)	0.003	0.037	0.08	0.94	-0.069	0.075
Lag5(Quantity traded at Ask)	0.057	0.036	1.56	0.12	-0.015	0.128
Lag6(Quantity traded at Ask)	-0.038	0.036	-1.05	0.29	-0.108	0.033
Time (in sec from Open)	0.016	0.088	0.18	0.86	-0.156	0.188
Time^2 (in sec from Open)	0.139	0.152	0.92	0.36	-0.158	0.437
Time^3 (in sec from Open)	0.012	0.055	0.21	0.84	-0.097	0.120
Time^4 (in sec from Open)	-0.051	0.067	-0.76	0.45	-0.183	0.081
Ttues Dummy	0.088	0.115	0.77	0.44	-0.137	0.313
Wed Dummy	0.133	0.109	1.21	0.23	-0.082	0.347
Thurs Dummy	0.051	0.117	0.43	0.67	-0.180	0.281
Fri Dummy	-0.043	0.110	-0.39	0.70	-0.258	0.172
First Trading Day of Month	-0.139	0.152	-0.91	0.36	-0.437	0.159
Last Trading Day of Month	0.167	0.217	0.77	0.44	-0.258	0.593
Lag(Change in Bid Price)	-12.786	5.139	-2.49	0.01	-22.867	-2.706
Lag2(Change in Bid Price)	-7.035	6.017	-1.17	0.24	-18.838	4.768
Lag3(Change in Bid Price)	-15.728	6.189	-2.54	0.01	-27.868	-3.587
Lag4(Change in Bid Price)	-10.289	6.203	-1.66	0.10	-22.457	1.879
Lag5(Change in Bid Price)	-7.104	6.057	-1.17	0.24	-18.985	4.777
Lag6(Change in Bid Price)	-8.277	5.166	-1.60	0.11	-18.410	1.857
dbestask						
Lag(Change in Ask Price)	15.337	5.370	2.86	0.00	4.803	25.871
Lag2(Change in Ask Price)	14.902	6.360	2.34	0.02	2.427	27.377
Lag3(Change in Ask Price)	12.905	6.530	1.98	0.05	0.096	25.714
Lag4(Change in Ask Price)	8.097	6.512	1.24	0.21	-4.676	20.870
Lag5(Change in Ask Price)	7.182	6.306	1.14	0.26	-5.188	19.552
Lag6(Change in Ask Price)	6.061	5.315	1.14	0.25	-4.366	16.487
Constant	-0.038	0.125	-0.30	0.76	-0.283	0.207

MBL

Obs	26084
R-squared	0.24
Adj R-squared	0.0227

Dep. Var: Size of Run	Coef.	Std. Error	t	P>|t|	[95% Conf. Interval]	
Last trade at Bid Price	-0.052	0.031	-1.67	0.09	-0.114	0.009
Lag(Quantity traded at Bid)	0.004	0.009	0.41	0.68	-0.014	0.021
Lag2(Quantity traded at Bid)	0.087	0.009	9.69	0.00	0.069	0.104
Lag3(Quantity traded at Bid)	0.032	0.009	3.59	0.00	0.015	0.050
Lag3(Quantity traded at Bid)	0.048	0.009	5.35	0.00	0.030	0.066
Lag4(Quantity traded at Bid)	0.011	0.009	1.25	0.21	-0.006	0.029
Lag5(Quantity traded at Bid)	0.044	0.009	4.90	0.00	0.026	0.061
lqatask						
Quantity traded at Ask	-0.001	0.009	-0.16	0.87	-0.019	0.016
Lag(Quantity traded at Ask)	0.079	0.009	8.78	0.00	0.062	0.097
Lag2(Quantity traded at Ask)	-0.011	0.009	-1.26	0.21	-0.029	0.006
Lag3(Quantity traded at Ask)	0.069	0.009	7.61	0.00	0.051	0.087
Lag4(Quantity traded at Ask)	0.025	0.009	2.76	0.01	0.007	0.043
Lag5(Quantity traded at Ask)	0.063	0.009	7.02	0.00	0.046	0.081
Lag6(Quantity traded at Ask)	-0.003	0.009	-0.40	0.69	-0.021	0.014
Time (in sec from Open)	0.026	0.022	1.16	0.24	-0.017	0.068
Time^2 (in sec from Open)	0.128	0.041	3.12	0.00	0.048	0.208
Time^3 (in sec from Open)	-0.008	0.014	-0.61	0.54	-0.035	0.018
Time^4 (in sec from Open)	-0.027	0.018	-1.49	0.14	-0.063	0.009
Ttues Dummy	-0.025	0.026	-0.96	0.34	-0.076	0.026
Wed Dummy	0.094	0.025	3.77	0.00	0.045	0.142
Thurs Dummy	0.052	0.025	2.05	0.04	0.002	0.101
Fri Dummy	0.030	0.026	1.15	0.25	-0.021	0.082
First Trading Day of Month	-0.089	0.047	-1.88	0.06	-0.182	0.004
Last Trading Day of Month	-0.144	0.053	-2.74	0.01	-0.248	-0.041
Lag(Change in Bid Price)	-0.879	0.341	-2.58	0.01	-1.548	-0.211
Lag2(Change in Bid Price)	0.416	0.412	1.01	0.31	-0.391	1.224
Lag3(Change in Bid Price)	0.059	0.426	0.14	0.89	-0.777	0.895
Lag4(Change in Bid Price)	-0.359	0.425	-0.84	0.40	-1.193	0.474
Lag5(Change in Bid Price)	-0.450	0.411	-1.10	0.27	-1.255	0.356
Lag6(Change in Bid Price)	-0.285	0.342	-0.83	0.41	-0.956	0.386
dbestask						
Lag(Change in Ask Price)	0.822	0.348	2.36	0.02	0.140	1.503
Lag2(Change in Ask Price)	-0.130	0.411	-0.32	0.75	-0.937	0.676
Lag3(Change in Ask Price)	-0.262	0.426	-0.62	0.54	-1.097	0.573
Lag4(Change in Ask Price)	-0.291	0.426	-0.68	0.50	-1.127	0.545
Lag5(Change in Ask Price)	-0.323	0.411	-0.79	0.43	-1.129	0.483
Lag6(Change in Ask Price)	0.100	0.344	0.29	0.77	-0.574	0.774
Constant	-0.093	0.029	-3.17	0.00	-0.150	-0.036

NWS

Obs	9256
R-squared	0.0228
Adj R-squared	0.019

Dep. Var: Size of Run	**Coef.**	**Std. Error**	**t**	**P>|t|**	**[95% Conf. Interval]**	
Last trade at Bid Price	-0.097	0.054	-1.78	0.08	-0.203	0.010
Lag(Quantity traded at Bid)	0.021	0.015	1.35	0.18	-0.009	0.050
Lag2(Quantity traded at Bid)	0.057	0.015	3.76	0.00	0.027	0.087
Lag3(Quantity traded at Bid)	0.019	0.015	1.24	0.21	-0.011	0.049
Lag3(Quantity traded at Bid)	0.053	0.015	3.49	0.00	0.023	0.083
Lag4(Quantity traded at Bid)	0.008	0.015	0.52	0.60	-0.022	0.038
Lag5(Quantity traded at Bid)	0.054	0.015	3.55	0.00	0.024	0.084
lqatask						
Quantity traded at Ask	0.019	0.015	1.32	0.19	-0.009	0.048
Lag(Quantity traded at Ask)	0.020	0.015	1.35	0.18	-0.009	0.048
Lag2(Quantity traded at Ask)	-0.001	0.015	-0.08	0.94	-0.030	0.028
Lag3(Quantity traded at Ask)	0.085	0.015	5.85	0.00	0.057	0.114
Lag4(Quantity traded at Ask)	0.019	0.015	1.29	0.20	-0.010	0.048
Lag5(Quantity traded at Ask)	0.048	0.015	3.28	0.00	0.019	0.077
Lag6(Quantity traded at Ask)	0.014	0.014	0.99	0.32	-0.014	0.043
Time (in sec from Open)	-0.063	0.038	-1.68	0.09	-0.137	0.011
Time^2 (in sec from Open)	0.261	0.071	3.65	0.00	0.120	0.401
Time^3 (in sec from Open)	0.057	0.024	2.39	0.02	0.010	0.103
Time^4 (in sec from Open)	-0.074	0.032	-2.28	0.02	-0.137	-0.010
Ttues Dummy	-0.035	0.045	-0.79	0.43	-0.123	0.052
Wed Dummy	0.000	0.042	0.00	1.00	-0.083	0.083
Thurs Dummy	0.016	0.042	0.39	0.70	-0.067	0.099
Fri Dummy	-0.069	0.045	-1.54	0.12	-0.156	0.019
First Trading Day of Month	0.062	0.072	0.86	0.39	-0.080	0.204
Last Trading Day of Month	-0.002	0.077	-0.02	0.98	-0.152	0.149
Lag(Change in Bid Price)	-1.088	1.598	-0.68	0.50	-4.221	2.045
Lag2(Change in Bid Price)	-0.799	1.918	-0.42	0.68	-4.559	2.960
Lag3(Change in Bid Price)	2.795	1.993	1.40	0.16	-1.112	6.702
Lag4(Change in Bid Price)	2.695	1.988	1.36	0.18	-1.202	6.592
Lag5(Change in Bid Price)	2.640	1.914	1.38	0.17	-1.112	6.393
Lag6(Change in Bid Price)	1.264	1.596	0.79	0.43	-1.865	4.392
dbestask						
Lag(Change in Ask Price)	0.192	1.705	0.11	0.91	-3.150	3.534
Lag2(Change in Ask Price)	1.620	2.019	0.80	0.42	-2.339	5.578
Lag3(Change in Ask Price)	-2.229	2.092	-1.07	0.29	-6.331	1.872
Lag4(Change in Ask Price)	-2.811	2.087	-1.35	0.18	-6.901	1.279
Lag5(Change in Ask Price)	-1.476	2.006	-0.74	0.46	-5.408	2.456
Lag6(Change in Ask Price)	-0.709	1.692	-0.42	0.68	-4.025	2.608
Constant	-0.086	0.050	-1.72	0.09	-0.185	0.012

ZFX

Obs	17246
R-squared	0.0202
Adj R-squared	0.0182

Dep. Var: Size of Run	**Coef.**	**Std. Error**	**t**	**P>|t|**	**[95% Conf. Interval]**	
Last trade at Bid Price	0.017	0.041	0.42	0.68	-0.064	0.098
Lag(Quantity traded at Bid)	-0.004	0.011	-0.37	0.71	-0.026	0.018
Lag2(Quantity traded at Bid)	0.077	0.011	6.95	0.00	0.055	0.099
Lag3(Quantity traded at Bid)	-0.009	0.011	-0.83	0.41	-0.031	0.013
Lag3(Quantity traded at Bid)	0.040	0.011	3.65	0.00	0.019	0.062
Lag4(Quantity traded at Bid)	0.008	0.011	0.77	0.44	-0.013	0.030
Lag5(Quantity traded at Bid)	0.037	0.011	3.34	0.00	0.015	0.059
lqatask						
Quantity traded at Ask	-0.008	0.011	-0.68	0.49	-0.029	0.014
Lag(Quantity traded at Ask)	0.072	0.011	6.54	0.00	0.050	0.094
Lag2(Quantity traded at Ask)	0.010	0.011	0.91	0.36	-0.012	0.032
Lag3(Quantity traded at Ask)	0.067	0.011	6.06	0.00	0.045	0.088
Lag4(Quantity traded at Ask)	0.044	0.011	4.03	0.00	0.023	0.066
Lag5(Quantity traded at Ask)	0.056	0.011	5.12	0.00	0.035	0.078
Lag6(Quantity traded at Ask)	0.000	0.011	-0.04	0.97	-0.022	0.021
Time (in sec from Open)	-0.023	0.031	-0.74	0.46	-0.084	0.038
Time^2 (in sec from Open)	0.102	0.053	1.91	0.06	-0.003	0.206
Time^3 (in sec from Open)	0.048	0.023	2.11	0.04	0.003	0.093
Time^4 (in sec from Open)	-0.045	0.026	-1.71	0.09	-0.096	0.006
Ttues Dummy	-0.072	0.032	-2.24	0.03	-0.136	-0.009
Wed Dummy	-0.003	0.031	-0.08	0.94	-0.063	0.058
Thurs Dummy	0.102	0.032	3.15	0.00	0.039	0.166
Fri Dummy	0.042	0.032	1.31	0.19	-0.021	0.105
First Trading Day of Month	0.053	0.048	1.09	0.28	-0.042	0.147
Last Trading Day of Month	-0.125	0.059	-2.13	0.03	-0.240	-0.010
Lag(Change in Bid Price)	-3.705	2.075	-1.79	0.07	-7.772	0.362
Lag2(Change in Bid Price)	-0.071	2.533	-0.03	0.98	-5.036	4.894
Lag3(Change in Bid Price)	-1.175	2.633	-0.45	0.66	-6.337	3.987
Lag4(Change in Bid Price)	-1.087	2.633	-0.41	0.68	-6.248	4.073
Lag5(Change in Bid Price)	-0.458	2.531	-0.18	0.86	-5.418	4.503
Lag6(Change in Bid Price)	-2.012	2.073	-0.97	0.33	-6.076	2.052
dbestask						
Lag(Change in Ask Price)	3.698	2.067	1.79	0.07	-0.353	7.749
Lag2(Change in Ask Price)	-0.151	2.522	-0.06	0.95	-5.095	4.792
Lag3(Change in Ask Price)	2.049	2.625	0.78	0.44	-3.096	7.195
Lag4(Change in Ask Price)	-0.290	2.628	-0.11	0.91	-5.441	4.862
Lag5(Change in Ask Price)	-1.242	2.524	-0.49	0.62	-6.189	3.705
Lag6(Change in Ask Price)	0.534	2.077	0.26	0.80	-3.538	4.606
Constant	-0.066	0.038	-1.75	0.08	-0.140	0.008

6.1.2 Forecasting Variance of Run Sizes

IVC

Obs	1630
R-squared	0.1075
Adj R-squared	0.0838

Dep. Var: Size of Run	**Coef.**	**0.0838**	**Err.**	**t**	**P>|t|**	**[95%**
Last trade at Bid Price	0.027	0.815	0.03	0.97	-1.571	1.626
Lag(Quantity traded at Bid)	-0.177	0.381	-0.47	0.64	-0.924	0.570
Lag2(Quantity traded at Bid)	-0.322	0.382	-0.84	0.40	-1.070	0.427
Lag3(Quantity traded at Bid)	0.618	0.380	1.62	0.11	-0.128	1.364
Lag3(Quantity traded at Bid)	1.473	0.381	3.87	0.00	0.726	2.221
Lag4(Quantity traded at Bid)	-0.146	0.383	-0.38	0.70	-0.896	0.605
Lag5(Quantity traded at Bid)	-0.288	0.382	-0.75	0.45	-1.038	0.462
Iqatask						
Quantity traded at Ask	-0.290	0.324	-0.89	0.37	-0.926	0.346
Lag(Quantity traded at Ask)	-1.545	0.321	-4.81	0.00	-2.175	-0.915
Lag2(Quantity traded at Ask)	0.188	0.331	0.57	0.57	-0.462	0.837
Lag3(Quantity traded at Ask)	1.430	0.329	4.35	0.00	0.786	2.075
Lag4(Quantity traded at Ask)	-0.070	0.323	-0.22	0.83	-0.703	0.562
Lag5(Quantity traded at Ask)	-0.074	0.321	-0.23	0.82	-0.703	0.556
Lag6(Quantity traded at Ask)	0.049	0.258	0.19	0.85	-0.457	0.556
Time (in sec from Open)	-0.554	0.701	-0.79	0.43	-1.928	0.820
Time^2 (in sec from Open)	0.025	1.119	0.02	0.98	-2.170	2.219
Time^3 (in sec from Open)	0.412	0.536	0.77	0.44	-0.639	1.463
Time^4 (in sec from Open)	0.045	0.519	0.09	0.93	-0.974	1.063
Ttues Dummy	-0.292	0.696	-0.42	0.68	-1.657	1.074
Wed Dummy	-0.181	0.697	-0.26	0.80	-1.548	1.186
Thurs Dummy	1.049	0.735	1.43	0.15	-0.392	2.491
Fri Dummy	0.495	0.747	0.66	0.51	-0.971	1.961
First Trading Day of Month	-0.435	1.115	-0.39	0.70	-2.622	1.752
Last Trading Day of Month	0.664	1.330	0.50	0.62	-1.944	3.273
Lag(Change in Bid Price)	0.076	26.592	0.00	1.00	-52.084	52.236
Lag2(Change in Bid Price)	4.085	31.150	0.13	0.90	-57.015	65.184
Lag3(Change in Bid Price)	-9.342	32.482	-0.29	0.77	-73.054	54.369
Lag4(Change in Bid Price)	-6.436	32.471	-0.20	0.84	-70.126	57.254
Lag5(Change in Bid Price)	-7.407	31.180	-0.24	0.81	-68.565	53.751
Lag6(Change in Bid Price)	-28.151	26.669	-1.06	0.29	-80.462	24.160
dbestask						
Lag(Change in Ask Price)	0.004	26.563	0.00	1.00	-52.099	52.106
Lag2(Change in Ask Price)	29.295	30.848	0.95	0.34	-31.213	89.803
Lag3(Change in Ask Price)	10.887	31.993	0.34	0.73	-51.866	73.640
Lag4(Change in Ask Price)	-0.598	31.960	-0.02	0.99	-63.287	62.090
Lag5(Change in Ask Price)	18.600	30.726	0.61	0.55	-41.667	78.867
Lag6(Change in Ask Price)	41.406	26.313	1.57	0.12	-10.206	93.017
Lag(sigma_run)	0.022	0.041	0.54	0.59	-0.058	0.102
Lag2(sigma_run)	0.382	0.041	9.39	0.00	0.302	0.462
Lag3(sigma_run)	-0.045	0.042	-1.07	0.28	-0.128	0.038
Lag4(sigma_run)	-0.234	0.042	-5.53	0.00	-0.317	-0.151
Lag5(sigma_run)	-0.002	0.041	-0.04	0.97	-0.083	0.080
Lag6(sigma_run)	0.041	0.041	0.98	0.33	-0.040	0.122
Constant	1.058	0.822	1.29	0.20	-0.555	2.670

AWC

Obs	14367
R-squared	0.0234
Adj R-squared	0.0206

Dep. Var: Size of Run	**Coef.**	**Std.**	**Err.**	**t**	**P>|t|**	**[95%**
Last trade at Bid Price	0.355	0.289	1.23	0.22	-0.211	0.922
Lag(Quantity traded at Bid)	-0.170	0.086	-1.97	0.05	-0.340	-0.001
Lag2(Quantity traded at Bid)	0.208	0.086	2.41	0.02	0.039	0.377
Lag3(Quantity traded at Bid)	0.231	0.087	2.67	0.01	0.061	0.401
Lag3(Quantity traded at Bid)	-0.020	0.087	-0.23	0.82	-0.190	0.150
Lag4(Quantity traded at Bid)	-0.076	0.086	-0.88	0.38	-0.245	0.093
Lag5(Quantity traded at Bid)	-0.140	0.086	-1.63	0.10	-0.309	0.029
lqatask						
Quantity traded at Ask	-0.002	0.093	-0.02	0.98	-0.184	0.180
Lag(Quantity traded at Ask)	0.059	0.093	0.64	0.52	-0.123	0.242
Lag2(Quantity traded at Ask)	-0.057	0.093	-0.61	0.54	-0.240	0.126
Lag3(Quantity traded at Ask)	0.065	0.093	0.69	0.49	-0.118	0.247
Lag4(Quantity traded at Ask)	-0.031	0.093	-0.33	0.74	-0.213	0.151
Lag5(Quantity traded at Ask)	-0.038	0.093	-0.41	0.69	-0.219	0.144
Lag6(Quantity traded at Ask)	0.407	0.073	5.59	0.00	0.265	0.550
Time (in sec from Open)	-0.148	0.191	-0.78	0.44	-0.522	0.226
Time^2 (in sec from Open)	-0.138	0.359	-0.39	0.70	-0.841	0.565
Time^3 (in sec from Open)	0.191	0.126	1.52	0.13	-0.056	0.439
Time^4 (in sec from Open)	0.001	0.168	0.01	0.99	-0.329	0.332
Ttues Dummy	0.190	0.207	0.92	0.36	-0.215	0.595
Wed Dummy	-0.140	0.196	-0.71	0.48	-0.524	0.245
Thurs Dummy	0.105	0.204	0.51	0.61	-0.296	0.505
Fri Dummy	0.306	0.205	1.49	0.14	-0.096	0.707
First Trading Day of Month	-0.255	0.330	-0.77	0.44	-0.901	0.391
Last Trading Day of Month	2.212	0.384	5.77	0.00	1.460	2.965
Lag(Change in Bid Price)	4.341	15.883	0.27	0.79	-26.793	35.474
Lag2(Change in Bid Price)	1.997	19.098	0.11	0.92	-35.437	39.432
Lag3(Change in Bid Price)	12.286	19.831	0.62	0.54	-26.586	51.157
Lag4(Change in Bid Price)	-7.087	19.820	-0.36	0.72	-45.937	31.763
Lag5(Change in Bid Price)	-2.638	19.126	-0.14	0.89	-40.127	34.852
Lag6(Change in Bid Price)	-6.779	15.926	-0.43	0.67	-37.995	24.438
dbestask						
Lag(Change in Ask Price)	-6.493	16.635	-0.39	0.70	-39.099	26.114
Lag2(Change in Ask Price)	0.654	19.706	0.03	0.97	-37.973	39.281
Lag3(Change in Ask Price)	-3.133	20.420	-0.15	0.88	-43.159	36.893
Lag4(Change in Ask Price)	7.047	20.405	0.35	0.73	-32.950	47.044
Lag5(Change in Ask Price)	1.910	19.615	0.10	0.92	-36.538	40.358
Lag6(Change in Ask Price)	8.162	16.465	0.50	0.62	-24.112	40.437
Lag(sigma_run)	0.027	0.012	2.34	0.02	0.004	0.050
Lag2(sigma_run)	0.028	0.012	2.37	0.02	0.005	0.050
Lag3(sigma_run)	0.036	0.012	3.13	0.00	0.014	0.059
Lag4(sigma_run)	0.025	0.012	2.10	0.04	0.002	0.047
Lag5(sigma_run)	0.011	0.012	0.94	0.35	-0.012	0.034
Lag6(sigma_run)	0.094	0.012	8.04	0.00	0.071	0.116
Constant	0.975	0.252	3.87	0.00	0.481	1.468

BBG

Obs	5490
R-squared	0.0215
Adj R-squared	0.014

Dep. Var: Size of Run	**Coef.**	**Std.**	**Err.**	**t**	**P>|t|**	**[95%**
Last trade at Bid Price	-1.126	0.429	-2.63	0.01	-1.967	-0.286
Lag(Quantity traded at Bid)	0.134	0.147	0.91	0.36	-0.155	0.423
Lag2(Quantity traded at Bid)	0.362	0.148	2.45	0.01	0.072	0.651
Lag3(Quantity traded at Bid)	0.210	0.148	1.41	0.16	-0.081	0.500
Lag3(Quantity traded at Bid)	-0.255	0.149	-1.72	0.09	-0.546	0.036
Lag4(Quantity traded at Bid)	-0.161	0.147	-1.09	0.28	-0.450	0.128
Lag5(Quantity traded at Bid)	0.133	0.147	0.91	0.37	-0.155	0.421
lqatask						
Quantity traded at Ask	0.011	0.145	0.07	0.94	-0.275	0.296
Lag(Quantity traded at Ask)	0.376	0.146	2.58	0.01	0.090	0.662
Lag2(Quantity traded at Ask)	0.258	0.146	1.77	0.08	-0.028	0.545
Lag3(Quantity traded at Ask)	0.689	0.146	4.72	0.00	0.403	0.974
Lag4(Quantity traded at Ask)	0.031	0.147	0.21	0.83	-0.257	0.319
Lag5(Quantity traded at Ask)	0.331	0.146	2.27	0.02	0.045	0.617
Lag6(Quantity traded at Ask)	0.062	0.121	0.51	0.61	-0.176	0.299
Time (in sec from Open)	0.442	0.306	1.44	0.15	-0.159	1.043
Time^2 (in sec from Open)	-0.276	0.561	-0.49	0.62	-1.376	0.825
Time^3 (in sec from Open)	-0.187	0.209	-0.90	0.37	-0.596	0.222
Time^4 (in sec from Open)	0.187	0.257	0.73	0.47	-0.317	0.692
Ttues Dummy	-0.142	0.334	-0.43	0.67	-0.797	0.513
Wed Dummy	0.178	0.335	0.53	0.60	-0.479	0.835
Thurs Dummy	-0.272	0.363	-0.75	0.45	-0.984	0.440
Fri Dummy	-0.433	0.343	-1.26	0.21	-1.106	0.239
First Trading Day of Month	0.470	0.512	0.92	0.36	-0.533	1.473
Last Trading Day of Month	-0.650	0.703	-0.93	0.36	-2.029	0.728
Lag(Change in Bid Price)	2.869	6.252	0.46	0.65	-9.387	15.125
Lag2(Change in Bid Price)	10.006	7.662	1.31	0.19	-5.015	25.026
Lag3(Change in Bid Price)	-1.903	8.025	-0.24	0.81	-17.634	13.829
Lag4(Change in Bid Price)	3.938	8.026	0.49	0.62	-11.796	19.672
Lag5(Change in Bid Price)	0.171	7.677	0.02	0.98	-14.879	15.221
Lag6(Change in Bid Price)	6.789	6.264	1.08	0.28	-5.490	19.069
dbestask						
Lag(Change in Ask Price)	-3.958	6.936	-0.57	0.57	-17.554	9.639
Lag2(Change in Ask Price)	-10.189	8.173	-1.25	0.21	-26.210	5.833
Lag3(Change in Ask Price)	1.570	8.498	0.19	0.85	-15.090	18.229
Lag4(Change in Ask Price)	-7.378	8.440	-0.87	0.38	-23.923	9.167
Lag5(Change in Ask Price)	-5.935	8.061	-0.74	0.46	-21.739	9.868
Lag6(Change in Ask Price)	-8.741	6.763	-1.29	0.20	-22.000	4.518
Lag(sigma_run)	-0.003	0.018	-0.16	0.88	-0.038	0.032
Lag2(sigma_run)	-0.016	0.018	-0.89	0.37	-0.051	0.019
Lag3(sigma_run)	-0.016	0.018	-0.88	0.38	-0.051	0.019
Lag4(sigma_run)	0.035	0.018	1.95	0.05	0.000	0.070
Lag5(sigma_run)	0.005	0.018	0.28	0.78	-0.030	0.040
Lag6(sigma_run)	-0.020	0.018	-1.10	0.27	-0.055	0.015
Constant	2.138	0.417	5.13	0.00	1.320	2.955

GWT

Obs	1556
R-squared	0.0317
Adj R-squared	0.0049

Dep. Var: Size of Run	**Coef.**	**Std.**	**Err.**	**t**	**P>|t|**	**[95%**
Last trade at Bid Price	0.028	0.551	0.05	0.96	-1.052	1.108
Lag(Quantity traded at Bid)	0.118	0.190	0.62	0.54	-0.255	0.492
Lag2(Quantity traded at Bid)	0.345	0.191	1.81	0.07	-0.029	0.719
Lag3(Quantity traded at Bid)	-0.161	0.191	-0.84	0.40	-0.536	0.215
Lag3(Quantity traded at Bid)	0.355	0.191	1.86	0.06	-0.020	0.731
Lag4(Quantity traded at Bid)	0.073	0.191	0.38	0.70	-0.303	0.449
Lag5(Quantity traded at Bid)	0.174	0.191	0.91	0.36	-0.201	0.549
lqatask						
Quantity traded at Ask	-0.110	0.203	-0.54	0.59	-0.508	0.287
Lag(Quantity traded at Ask)	0.531	0.202	2.63	0.01	0.135	0.926
Lag2(Quantity traded at Ask)	0.274	0.203	1.35	0.18	-0.124	0.673
Lag3(Quantity traded at Ask)	0.176	0.204	0.86	0.39	-0.223	0.575
Lag4(Quantity traded at Ask)	0.068	0.203	0.34	0.74	-0.331	0.467
Lag5(Quantity traded at Ask)	0.133	0.203	0.66	0.51	-0.265	0.530
Lag6(Quantity traded at Ask)	-0.093	0.146	-0.64	0.52	-0.379	0.193
Time (in sec from Open)	-0.113	0.359	-0.32	0.75	-0.816	0.591
Time^2 (in sec from Open)	0.271	0.619	0.44	0.66	-0.944	1.486
Time^3 (in sec from Open)	0.123	0.226	0.54	0.59	-0.321	0.567
Time^4 (in sec from Open)	-0.027	0.274	-0.10	0.92	-0.564	0.510
Ttues Dummy	0.328	0.467	0.70	0.48	-0.589	1.244
Wed Dummy	0.041	0.446	0.09	0.93	-0.835	0.917
Thurs Dummy	0.849	0.481	1.77	0.08	-0.094	1.793
Fri Dummy	0.186	0.450	0.41	0.68	-0.697	1.069
First Trading Day of Month	-0.092	0.637	-0.14	0.89	-1.342	1.158
Last Trading Day of Month	-0.283	0.887	-0.32	0.75	-2.023	1.458
Lag(Change in Bid Price)	-37.810	21.003	-1.80	0.07	-79.008	3.389
Lag2(Change in Bid Price)	-12.586	24.564	-0.51	0.61	-60.770	35.597
Lag3(Change in Bid Price)	-51.396	25.257	-2.04	0.04	-100.938	-1.853
Lag4(Change in Bid Price)	-39.621	25.323	-1.57	0.12	-89.292	10.050
Lag5(Change in Bid Price)	-14.165	24.695	-0.57	0.57	-62.606	34.276
Lag6(Change in Bid Price)	-8.353	21.066	-0.40	0.69	-49.675	32.969
dbestask						
Lag(Change in Ask Price)	51.489	21.945	2.35	0.02	8.444	94.534
Lag2(Change in Ask Price)	33.368	25.955	1.29	0.20	-17.544	84.280
Lag3(Change in Ask Price)	44.607	26.647	1.67	0.09	-7.662	96.875
Lag4(Change in Ask Price)	33.825	26.590	1.27	0.20	-18.331	85.982
Lag5(Change in Ask Price)	10.097	25.727	0.39	0.70	-40.367	60.562
Lag6(Change in Ask Price)	7.847	21.687	0.36	0.72	-34.693	50.386
Lag(sigma_run)	0.002	0.041	0.04	0.97	-0.078	0.081
Lag2(sigma_run)	-0.044	0.040	-1.08	0.28	-0.123	0.036
Lag3(sigma_run)	-0.003	0.041	-0.09	0.93	-0.083	0.076
Lag4(sigma_run)	0.004	0.041	0.11	0.92	-0.075	0.084
Lag5(sigma_run)	-0.008	0.041	-0.19	0.85	-0.087	0.072
Lag6(sigma_run)	-0.021	0.041	-0.51	0.61	-0.100	0.059
Constant	1.026	0.526	1.95	0.05	-0.006	2.058

MBL

Obs	26072
R-squared	0.0069
Adj R-squared	0.0053

Dep. Var: Size of Run	**Coef.**	**Std.**	**Err.**	**t**	**P>|t|**	**[95%**
Last trade at Bid Price	-0.363	0.229	-1.58	0.11	-0.812	0.086
Lag(Quantity traded at Bid)	-0.099	0.083	-1.20	0.23	-0.261	0.063
Lag2(Quantity traded at Bid)	0.447	0.083	5.41	0.00	0.285	0.608
Lag3(Quantity traded at Bid)	0.161	0.083	1.94	0.05	-0.001	0.323
Lag3(Quantity traded at Bid)	0.164	0.083	1.99	0.05	0.002	0.327
Lag4(Quantity traded at Bid)	0.028	0.083	0.34	0.74	-0.134	0.190
Lag5(Quantity traded at Bid)	0.194	0.082	2.36	0.02	0.033	0.356
lqatask						
Quantity traded at Ask	-0.209	0.076	-2.74	0.01	-0.358	-0.059
Lag(Quantity traded at Ask)	0.405	0.076	5.32	0.00	0.256	0.555
Lag2(Quantity traded at Ask)	-0.083	0.076	-1.09	0.28	-0.233	0.067
Lag3(Quantity traded at Ask)	0.250	0.076	3.27	0.00	0.100	0.399
Lag4(Quantity traded at Ask)	0.130	0.076	1.70	0.09	-0.020	0.280
Lag5(Quantity traded at Ask)	0.321	0.076	4.21	0.00	0.171	0.470
Lag6(Quantity traded at Ask)	-0.055	0.064	-0.86	0.39	-0.180	0.071
Time (in sec from Open)	0.217	0.160	1.36	0.17	-0.096	0.530
Time^2 (in sec from Open)	0.096	0.299	0.32	0.75	-0.489	0.681
Time^3 (in sec from Open)	-0.157	0.099	-1.59	0.11	-0.351	0.037
Time^4 (in sec from Open)	0.027	0.134	0.20	0.84	-0.235	0.289
Ttues Dummy	-0.086	0.189	-0.45	0.65	-0.455	0.284
Wed Dummy	0.341	0.181	1.88	0.06	-0.014	0.696
Thurs Dummy	0.017	0.183	0.09	0.93	-0.342	0.376
Fri Dummy	0.048	0.192	0.25	0.80	-0.329	0.424
First Trading Day of Month	-0.358	0.347	-1.03	0.30	-1.037	0.322
Last Trading Day of Month	-0.072	0.384	-0.19	0.85	-0.824	0.681
Lag(Change in Bid Price)	-5.951	2.485	-2.40	0.02	-10.821	-1.081
Lag2(Change in Bid Price)	-0.843	3.003	-0.28	0.78	-6.730	5.043
Lag3(Change in Bid Price)	-2.030	3.107	-0.65	0.51	-8.119	4.060
Lag4(Change in Bid Price)	-5.985	3.098	-1.93	0.05	-12.056	0.086
Lag5(Change in Bid Price)	-4.606	2.993	-1.54	0.12	-10.472	1.260
Lag6(Change in Bid Price)	-0.969	2.494	-0.39	0.70	-5.858	3.920
dbestask						
Lag(Change in Ask Price)	7.085	2.534	2.80	0.01	2.119	12.051
Lag2(Change in Ask Price)	-0.452	2.997	-0.15	0.88	-6.326	5.423
Lag3(Change in Ask Price)	2.017	3.103	0.65	0.52	-4.066	8.099
Lag4(Change in Ask Price)	2.299	3.105	0.74	0.46	-3.786	8.384
Lag5(Change in Ask Price)	2.093	2.994	0.70	0.48	-3.774	7.961
Lag6(Change in Ask Price)	0.373	2.505	0.15	0.88	-4.536	5.282
Lag(sigma_run)	0.010	0.009	1.12	0.26	-0.007	0.027
Lag2(sigma_run)	-0.027	0.009	-3.07	0.00	-0.044	-0.010
Lag3(sigma_run)	-0.004	0.009	-0.51	0.61	-0.022	0.013
Lag4(sigma_run)	-0.012	0.009	-1.40	0.16	-0.029	0.005
Lag5(sigma_run)	-0.004	0.009	-0.43	0.67	-0.021	0.013
Lag6(sigma_run)	0.000	0.009	-0.03	0.98	-0.017	0.017
Constant	1.604	0.218	7.36	0.00	1.177	2.031

NWS

Obs	9250
R-squared	0.0054
Adj R-squared	0.0009

Dep. Var: Size of Run	**Coef.**	**Std.**	**Err.**	**t**	**P>|t|**	**[95%**
Last trade at Bid Price	0.400	0.560	0.71	0.48	-0.698	1.498
Lag(Quantity traded at Bid)	0.047	0.164	0.29	0.77	-0.274	0.368
Lag2(Quantity traded at Bid)	0.240	0.164	1.46	0.14	-0.081	0.561
Lag3(Quantity traded at Bid)	0.141	0.164	0.86	0.39	-0.180	0.462
Lag3(Quantity traded at Bid)	0.253	0.164	1.54	0.12	-0.068	0.573
Lag4(Quantity traded at Bid)	-0.063	0.164	-0.38	0.70	-0.383	0.258
Lag5(Quantity traded at Bid)	0.076	0.163	0.47	0.64	-0.244	0.396
lqatask						
Quantity traded at Ask	0.157	0.197	0.79	0.43	-0.230	0.543
Lag(Quantity traded at Ask)	-0.051	0.197	-0.26	0.80	-0.437	0.335
Lag2(Quantity traded at Ask)	0.090	0.197	0.46	0.65	-0.297	0.476
Lag3(Quantity traded at Ask)	0.614	0.196	3.13	0.00	0.229	0.998
Lag4(Quantity traded at Ask)	0.106	0.197	0.54	0.59	-0.280	0.491
Lag5(Quantity traded at Ask)	-0.144	0.196	-0.73	0.46	-0.529	0.241
Lag6(Quantity traded at Ask)	0.019	0.148	0.13	0.90	-0.271	0.308
Time (in sec from Open)	-0.818	0.384	-2.13	0.03	-1.570	-0.066
Time^2 (in sec from Open)	0.064	0.728	0.09	0.93	-1.363	1.492
Time^3 (in sec from Open)	0.498	0.241	2.07	0.04	0.025	0.971
Time^4 (in sec from Open)	0.124	0.330	0.38	0.71	-0.522	0.770
Ttues Dummy	-0.047	0.455	-0.10	0.92	-0.938	0.845
Wed Dummy	0.072	0.431	0.17	0.87	-0.772	0.916
Thurs Dummy	0.361	0.431	0.84	0.40	-0.484	1.205
Fri Dummy	-0.347	0.454	-0.76	0.45	-1.236	0.543
First Trading Day of Month	0.073	0.741	0.10	0.92	-1.379	1.525
Last Trading Day of Month	-0.188	0.782	-0.24	0.81	-1.720	1.344
Lag(Change in Bid Price)	22.010	16.268	1.35	0.18	-9.880	53.899
Lag2(Change in Bid Price)	31.330	19.557	1.60	0.11	-7.005	69.666
Lag3(Change in Bid Price)	60.099	20.345	2.95	0.00	20.219	99.979
Lag4(Change in Bid Price)	63.517	20.342	3.12	0.00	23.643	103.391
Lag5(Change in Bid Price)	32.967	19.606	1.68	0.09	-5.465	71.400
Lag6(Change in Bid Price)	1.250	16.309	0.08	0.94	-30.720	33.220
dbestask						
Lag(Change in Ask Price)	-39.840	17.367	-2.29	0.02	-73.883	-5.797
Lag2(Change in Ask Price)	-31.527	20.614	-1.53	0.13	-71.935	8.881
Lag3(Change in Ask Price)	-59.280	21.379	-2.77	0.01	-101.187	-17.372
Lag4(Change in Ask Price)	-69.809	21.366	-3.27	0.00	-111.691	-27.927
Lag5(Change in Ask Price)	-28.385	20.555	-1.38	0.17	-68.677	11.907
Lag6(Change in Ask Price)	0.265	17.292	0.02	0.99	-33.632	34.162
Lag(sigma_run)	-0.012	0.014	-0.82	0.41	-0.040	0.016
Lag2(sigma_run)	-0.002	0.014	-0.16	0.87	-0.030	0.026
Lag3(sigma_run)	-0.010	0.014	-0.71	0.48	-0.038	0.018
Lag4(sigma_run)	-0.027	0.014	-1.92	0.06	-0.055	0.001
Lag5(sigma_run)	-0.006	0.014	-0.41	0.68	-0.034	0.022
Lag6(sigma_run)	0.017	0.014	1.20	0.23	-0.011	0.045
Constant	1.193	0.519	2.30	0.02	0.175	2.210

ZFX

Obs	17240
R-squared	0.0069
Adj R-squared	0.0045

Dep. Var: Size of Run	Coef.	Std.	Err.	t	P>|t|	[95%
Last trade at Bid Price	0.144	0.253	0.57	0.57	-0.351	0.640
Lag(Quantity traded at Bid)	-0.051	0.083	-0.62	0.54	-0.213	0.111
Lag2(Quantity traded at Bid)	0.351	0.083	4.24	0.00	0.189	0.514
Lag3(Quantity traded at Bid)	-0.044	0.083	-0.53	0.60	-0.207	0.119
Lag3(Quantity traded at Bid)	0.173	0.083	2.08	0.04	0.010	0.336
Lag4(Quantity traded at Bid)	0.042	0.083	0.51	0.61	-0.120	0.204
Lag5(Quantity traded at Bid)	0.202	0.083	2.45	0.02	0.040	0.365
lqatask						
Quantity traded at Ask	-0.086	0.084	-1.02	0.31	-0.251	0.079
Lag(Quantity traded at Ask)	0.137	0.084	1.62	0.10	-0.028	0.302
Lag2(Quantity traded at Ask)	-0.031	0.084	-0.37	0.71	-0.197	0.135
Lag3(Quantity traded at Ask)	0.143	0.084	1.69	0.09	-0.022	0.308
Lag4(Quantity traded at Ask)	0.273	0.084	3.24	0.00	0.108	0.439
Lag5(Quantity traded at Ask)	0.365	0.084	4.33	0.00	0.200	0.530
Lag6(Quantity traded at Ask)	-0.093	0.066	-1.41	0.16	-0.223	0.036
Time (in sec from Open)	-0.069	0.191	-0.36	0.72	-0.444	0.306
Time^2 (in sec from Open)	-0.549	0.328	-1.67	0.09	-1.192	0.094
Time^3 (in sec from Open)	0.075	0.140	0.53	0.59	-0.200	0.350
Time^4 (in sec from Open)	0.219	0.161	1.36	0.17	-0.096	0.534
Ttues Dummy	-0.200	0.198	-1.01	0.31	-0.589	0.188
Wed Dummy	0.134	0.188	0.71	0.48	-0.235	0.503
Thurs Dummy	0.299	0.199	1.50	0.13	-0.092	0.689
Fri Dummy	0.320	0.197	1.63	0.10	-0.066	0.707
First Trading Day of Month	0.223	0.296	0.75	0.45	-0.358	0.803
Last Trading Day of Month	-0.620	0.360	-1.72	0.09	-1.327	0.086
Lag(Change in Bid Price)	-13.869	12.742	-1.09	0.28	-38.845	11.106
Lag2(Change in Bid Price)	10.521	15.554	0.68	0.50	-19.966	41.008
Lag3(Change in Bid Price)	2.913	16.170	0.18	0.86	-28.783	34.608
Lag4(Change in Bid Price)	-3.702	16.167	-0.23	0.82	-35.390	27.986
Lag5(Change in Bid Price)	1.596	15.539	0.10	0.92	-28.863	32.054
Lag6(Change in Bid Price)	-2.334	12.731	-0.18	0.86	-27.289	22.621
dbestask						
Lag(Change in Ask Price)	10.241	12.692	0.81	0.42	-14.636	35.119
Lag2(Change in Ask Price)	-8.285	15.487	-0.54	0.59	-38.642	22.072
Lag3(Change in Ask Price)	-0.430	16.120	-0.03	0.98	-32.027	31.166
Lag4(Change in Ask Price)	3.120	16.140	0.19	0.85	-28.516	34.755
Lag5(Change in Ask Price)	-8.608	15.498	-0.56	0.58	-38.986	21.769
Lag6(Change in Ask Price)	-3.648	12.757	-0.29	0.78	-28.653	21.357
Lag(sigma_run)	0.005	0.011	0.45	0.65	-0.017	0.027
Lag2(sigma_run)	-0.004	0.011	-0.40	0.69	-0.026	0.017
Lag3(sigma_run)	0.005	0.011	0.44	0.66	-0.017	0.026
Lag4(sigma_run)	-0.004	0.011	-0.33	0.74	-0.025	0.018
Lag5(sigma_run)	-0.001	0.011	-0.13	0.90	-0.023	0.020
Lag6(sigma_run)	-0.022	0.011	-1.98	0.05	-0.043	0.000
Constant	1.597	0.238	6.72	0.00	1.131	2.063

6.1.3 VAR Regressions of Bid-Ask Spread and Order Book

IVC				AWC			
Equation	**Obs**	**R-sq**	**Chi2**	**Equation**	**Obs**	**R-sq**	**Chi2**
dbestbid	1636	0.392	1539	**dbestbid**	14373	0.404	13326
dbestask	1636	0.330	1292	**dbestask**	14373	0.371	12335
spread	1636	0.008	2407	**spread**	14373	0.062	23009
QD1	1636	0.331	922	**QD1**	14373	0.525	17646
QD2	1636	0.126	314	**QD2**	14373	0.388	10924
QD3	1636	0.249	646	**QD3**	14373	0.279	6685
QD4	1636	0.269	748	**QD4**	14373	0.383	11547
QD5	1636	0.385	1210	**QD5**	14373	0.401	10958
Q1	1636	0.345	963	**Q1**	14373	0.579	23521
Q2	1636	0.332	899	**Q2**	14373	0.561	23216
Q3	1636	0.366	1007	**Q3**	14373	0.516	20597
Q4	1636	0.187	490	**Q4**	14373	0.382	12471
Q5	1636	0.227	573	**Q5**	14373	0.459	13474
ind. Var	**Coef.**	**Std. Error**	**Z**	**ind. Var**	**Coef.**	**Std. Error**	**Z**
dbestbid				**dbestbid**			
buyinit	0.006364	0.001257	5.062	**buyinit**	0.006748	0.000486	13.893
qatask	0.003222	0.001429	2.255	**qatask**	-0.000063	0.000605	-0.103
qatbid	-0.003181	0.001219	-2.610	**qatbid**	-0.000449	0.000655	-0.686
qatask2	-0.000417	0.000204	-2.047	**qatask2**	-0.000130	0.000108	-1.201
qatbid2	0.000426	0.000139	3.064	**qatbid2**	0.000479	0.000107	4.473
askshock	0.004117	0.001374	2.997	**askshock**	0.003624	0.000587	6.178
bidshock	-0.002122	0.001190	-1.783	**bidshock**	-0.004500	0.000635	-7.093
sigmarun	-0.000276	0.000173	-1.597	**sigmarun**	-0.000116	0.000112	-1.038
dbestbid				**dbestbid**			
L1	-0.390344	0.016991	-22.973	**L1**	-0.318312	0.005784	-55.035
L2	-0.136145	0.018213	-7.475	**L2**	-0.023834	0.006070	-3.927
L3	-0.162378	0.018137	-8.953	**L3**	-0.058631	0.006050	-9.691
L4	-0.069260	0.018195	-3.807	**L4**	0.002890	0.006059	0.477
L5	-0.053174	0.017540	-3.032	**L5**	-0.027731	0.005945	-4.665
L6	-0.003616	0.012046	-0.300	**L6**	0.004696	0.004347	1.080
_cons	-0.002871	0.000880	-3.264	**_cons**	-0.003379	0.000321	-10.530
dbestask				**dbestask**			
buyinit	0.005342	0.001240	4.307	**buyinit**	0.005857	0.000462	12.687
qatask	0.002687	0.001431	1.878	**qatask**	0.000813	0.000577	1.409
qatbid	-0.001662	0.001224	-1.358	**qatbid**	0.000023	0.000624	0.037
qatask2	-0.000657	0.000205	-3.212	**qatask2**	-0.000221	0.000103	-2.144
qatbid2	0.000288	0.000140	2.062	**qatbid2**	0.000361	0.000102	3.536
askshock	0.005128	0.001374	3.731	**askshock**	0.002900	0.000559	5.186
bidshock	-0.003438	0.001194	-2.879	**bidshock**	-0.004493	0.000605	-7.429
sigmarun	-0.000101	0.000174	-0.581	**sigmarun**	-0.000022	0.000107	-0.202
dbestask				**dbestask**			
L1	-0.388881	0.017266	-22.522	**L1**	-0.311489	0.005849	-53.259
L2	-0.135747	0.018468	-7.351	**L2**	-0.020654	0.006122	-3.374
L3	-0.162514	0.018394	-8.835	**L3**	-0.054991	0.006101	-9.014
L4	-0.069318	0.018445	-3.758	**L4**	0.005220	0.006111	0.854
L5	-0.051981	0.017770	-2.925	**L5**	-0.027399	0.005999	-4.568
L6	-0.002882	0.012157	-0.237	**L6**	0.004302	0.004482	0.960
_cons	-0.002147	0.000876	-2.449	**_cons**	-0.002697	0.000304	-8.861

spread				**spread**			
buyinit	-0.001054	0.000633	-1.665	**buyinit**	-0.000906	0.000164	-5.532
qatask	-0.000536	0.000788	-0.680	**qatask**	0.000547	0.000214	2.558
qatbid	0.001335	0.000673	1.983	**qatbid**	0.000187	0.000232	0.803
qatask2	-0.000227	0.000113	-2.011	**qatask2**	-0.000074	0.000038	-1.923
qatbid2	-0.000129	0.000077	-1.680	**qatbid2**	-0.000102	0.000038	-2.696
askshock	0.000951	0.000755	1.260	**askshock**	-0.000427	0.000207	-2.061
bidshock	-0.001193	0.000657	-1.816	**bidshock**	0.000275	0.000225	1.221
sigmarun	0.000170	0.000096	1.773	**sigmarun**	0.000078	0.000040	1.963
spread				**spread**			
L1	0.518768	0.017531	29.591	**L1**	0.544737	0.006097	89.353
L2	0.220626	0.019576	11.270	**L2**	0.265953	0.006771	39.278
L3	-0.021950	0.019746	-1.112	**L3**	-0.022368	0.006910	-3.237
L4	0.077151	0.019744	3.908	**L4**	0.059220	0.006908	8.572
L5	0.014069	0.019497	0.722	**L5**	-0.017889	0.006760	-2.646
L6	0.045661	0.017825	2.562	**L6**	0.031943	0.006221	5.135
_cons	0.002743	0.000553	4.963	**_cons**	0.002078	0.000133	15.657
QD1				**QD1**			
buyinit	-0.239266	0.063264	-3.782	**buyinit**	-0.198784	0.029587	-6.719
qatask	-0.121829	0.080813	-1.508	**qatask**	-0.036910	0.039535	-0.934
qatbid	0.225016	0.069320	3.246	**qatbid**	0.255366	0.042742	5.975
qatask2	-0.004308	0.011211	-0.384	**qatask2**	-0.010043	0.006921	-1.451
qatbid2	-0.005465	0.007713	-0.709	**qatbid2**	-0.007425	0.006846	-1.085
askshock	-0.006065	0.077226	-0.079	**askshock**	0.026540	0.038316	0.693
bidshock	-0.230293	0.066591	-3.458	**bidshock**	-0.320477	0.041503	-7.722
sigmarun	0.015377	0.009564	1.608	**sigmarun**	0.003552	0.007159	0.496
QD1				**QD1**			
L1	0.374424	0.023802	15.731	**L1**	0.391791	0.008010	48.910
L2	0.225527	0.025671	8.785	**L2**	0.292900	0.008436	34.722
L3	0.008631	0.025923	0.333	**L3**	-0.013772	0.008670	-1.588
L4	0.027596	0.026061	1.059	**L4**	0.113862	0.008661	13.147
L5	-0.006378	0.025364	-0.251	**L5**	-0.002938	0.008434	-0.348
L6	0.045764	0.023857	1.918	**L6**	0.085468	0.007951	10.750
_cons	0.157240	0.046509	3.381	**_cons**	0.179569	0.020197	8.891
QD2				**QD2**			
buyinit	-0.059515	0.071616	-0.831	**buyinit**	0.092233	0.033318	2.768
qatask	-0.009210	0.089224	-0.103	**qatask**	0.076046	0.044102	1.724
qatbid	0.221198	0.076563	2.889	**qatbid**	0.187785	0.047698	3.937
qatask2	0.002331	0.012784	0.182	**qatask2**	-0.011450	0.007852	-1.458
qatbid2	-0.016173	0.008746	-1.849	**qatbid2**	-0.024830	0.007772	-3.195
askshock	-0.029025	0.085535	-0.339	**askshock**	-0.083091	0.042791	-1.942
bidshock	-0.094734	0.074462	-1.272	**bidshock**	-0.185324	0.046309	-4.002
sigmarun	0.007352	0.010884	0.675	**sigmarun**	0.026317	0.008117	3.242
QD2				**QD2**			
L1	0.221084	0.023692	9.332	**L1**	0.306558	0.007872	38.944
L2	0.187875	0.024097	7.797	**L2**	0.318382	0.008202	38.818
L3	0.049069	0.024418	2.010	**L3**	-0.010166	0.008536	-1.191
L4	0.024965	0.024509	1.019	**L4**	0.086992	0.008534	10.194
L5	0.048831	0.024083	2.028	**L5**	-0.002042	0.008198	-0.249
L6	0.014953	0.023886	0.626	**L6**	0.100607	0.007879	12.769
_cons	0.058616	0.052988	1.106	**_cons**	0.013120	0.022693	0.578

QD3				**QD3**			
buyinit	0.176996	0.066321	2.669	**buyinit**	-0.123859	0.036319	-3.410
qatask	-0.183253	0.083937	-2.183	**qatask**	0.200476	0.047560	4.215
qatbid	0.489185	0.071639	6.829	**qatbid**	-0.028504	0.051654	-0.552
qatask2	-0.008968	0.011955	-0.750	**qatask2**	0.017136	0.008533	2.008
qatbid2	-0.016009	0.008139	-1.967	**qatbid2**	0.012616	0.008440	1.495
askshock	0.096976	0.081091	1.196	**askshock**	-0.193664	0.046106	-4.200
bidshock	-0.510449	0.069744	-7.319	**bidshock**	0.015366	0.050051	0.307
sigmarun	0.019737	0.010179	1.939	**sigmarun**	-0.012738	0.008821	-1.444
QD3				**QD3**			
L1	0.204976	0.023607	8.683	**L1**	0.270151	0.007946	33.998
L2	0.351898	0.023380	15.052	**L2**	0.307686	0.008220	37.430
L3	0.015573	0.024859	0.626	**L3**	-0.031678	0.008521	-3.718
L4	0.047306	0.024745	1.912	**L4**	0.089338	0.008516	10.491
L5	-0.009248	0.023345	-0.396	**L5**	-0.001696	0.008193	-0.207
L6	0.000025	0.022943	0.001	**L6**	0.083195	0.007936	10.484
_cons	-0.001726	0.049122	-0.035	**_cons**	0.094029	0.024535	3.832
QD4				**QD4**			
buyinit	-0.031482	0.065285	-0.482	**buyinit**	-0.062620	0.033457	-1.872
qatask	-0.008905	0.081283	-0.110	**qatask**	0.067787	0.043936	1.543
qatbid	0.030054	0.069559	0.432	**qatbid**	-0.014133	0.047697	-0.296
qatask2	0.001154	0.011644	0.099	**qatask2**	0.013901	0.007875	1.765
qatbid2	0.000465	0.007949	0.059	**qatbid2**	0.015184	0.007789	1.949
askshock	-0.014012	0.078031	-0.180	**askshock**	-0.088313	0.042570	-2.075
bidshock	-0.044061	0.067855	-0.649	**bidshock**	0.003910	0.046217	0.085
sigmarun	0.000168	0.009889	0.017	**sigmarun**	-0.014265	0.008141	-1.752
QD4				**QD4**			
L1	0.390082	0.023702	16.458	**L1**	0.280135	0.007721	36.281
L2	0.213579	0.025358	8.422	**L2**	0.339327	0.007968	42.588
L3	-0.047055	0.025706	-1.831	**L3**	0.013400	0.008308	1.613
L4	0.089344	0.025733	3.472	**L4**	0.109666	0.008308	13.201
L5	-0.003885	0.025460	-0.153	**L5**	-0.007635	0.007967	-0.958
L6	0.056259	0.023786	2.365	**L6**	0.085767	0.007718	11.112
_cons	0.028175	0.048328	0.583	**_cons**	0.044132	0.022662	1.947
QD5				**QD5**			
buyinit	-0.146703	0.060420	-2.428	**buyinit**	0.000221	0.032999	0.007
qatask	0.229498	0.075517	3.039	**qatask**	0.088920	0.043339	2.052
qatbid	-0.243358	0.065062	-3.740	**qatbid**	0.058744	0.047026	1.249
qatask2	0.049968	0.010781	4.635	**qatask2**	-0.009124	0.007763	-1.175
qatbid2	0.039834	0.007371	5.404	**qatbid2**	-0.004633	0.007678	-0.603
askshock	-0.314300	0.072565	-4.331	**askshock**	-0.098971	0.042005	-2.356
bidshock	0.254648	0.063157	4.032	**bidshock**	-0.098137	0.045569	-2.154
sigmarun	-0.047478	0.009184	-5.170	**sigmarun**	0.009514	0.008026	1.185
QD5				**QD5**			
L1	0.345262	0.023585	14.639	**L1**	0.260821	0.008038	32.448
L2	0.305881	0.024802	12.333	**L2**	0.326910	0.008279	39.488
L3	-0.072498	0.025535	-2.839	**L3**	0.012718	0.008613	1.477
L4	0.131975	0.025623	5.151	**L4**	0.130977	0.008614	15.205
L5	0.036722	0.024441	1.502	**L5**	0.003689	0.008281	0.445
L6	0.017251	0.023609	0.731	**L6**	0.087049	0.008038	10.830
_cons	0.057706	0.044500	1.297	**_cons**	0.045549	0.022358	2.037

Q1				**Q1**			
buyinit	0.161665	0.062441	2.589	**buyinit**	0.068703	0.027741	2.477
qatask	0.002836	0.079410	0.036	**qatask**	0.116894	0.036839	3.173
qatbid	0.405757	0.068146	5.954	**qatbid**	0.174593	0.039706	4.397
qatask2	-0.014251	0.011057	-1.289	**qatask2**	-0.021893	0.006506	-3.365
qatbid2	-0.021491	0.007562	-2.842	**qatbid2**	-0.018071	0.006435	-2.808
askshock	0.054776	0.076368	0.717	**askshock**	-0.095576	0.035685	-2.678
bidshock	-0.133109	0.065838	-2.022	**bidshock**	-0.220396	0.038525	-5.721
sigmarun	0.009109	0.009408	0.968	**sigmarun**	0.022656	0.006727	3.368
Q1				**Q1**			
L1	0.133760	0.023676	5.650	**L1**	0.311641	0.007840	39.753
L2	0.564566	0.023934	23.588	**L2**	0.490040	0.008144	60.176
L3	-0.015557	0.026827	-0.580	**L3**	-0.066917	0.008996	-7.439
L4	-0.187177	0.026968	-6.941	**L4**	0.095516	0.008995	10.619
L5	0.044304	0.023763	1.864	**L5**	0.011890	0.008150	1.459
L6	0.104664	0.023698	4.417	**L6**	0.038453	0.007834	4.908
_cons	-0.037377	0.046314	-0.807	**_cons**	0.045264	0.018978	2.385
Q2				**Q2**			
buyinit	-0.147545	0.062916	-2.345	**buyinit**	-0.005996	0.028192	-0.213
qatask	0.358404	0.080726	4.440	**qatask**	0.090478	0.037225	2.431
qatbid	-0.057004	0.069177	-0.824	**qatbid**	0.104092	0.040385	2.577
qatask2	0.038449	0.011192	3.436	**qatask2**	-0.018056	0.006638	-2.720
qatbid2	0.041962	0.007655	5.482	**qatbid2**	-0.021440	0.006564	-3.266
askshock	-0.416482	0.077195	-5.395	**askshock**	-0.075921	0.036054	-2.106
bidshock	-0.026133	0.066808	-0.391	**bidshock**	-0.069436	0.039187	-1.772
sigmarun	-0.040692	0.009536	-4.267	**sigmarun**	0.015300	0.006863	2.229
Q2				**Q2**			
L1	0.303126	0.023656	12.814	**L1**	0.318294	0.007678	41.457
L2	0.233661	0.024811	9.418	**L2**	0.431431	0.007956	54.229
L3	0.010976	0.025267	0.434	**L3**	-0.039792	0.008529	-4.666
L4	-0.000785	0.025954	-0.030	**L4**	0.147024	0.008522	17.252
L5	0.014547	0.025492	0.571	**L5**	0.009361	0.007963	1.176
L6	0.112665	0.024868	4.530	**L6**	0.028617	0.007675	3.728
_cons	0.136301	0.046976	2.902	**_cons**	0.053559	0.019167	2.794
Q3				**Q3**			
buyinit	0.294289	0.061743	4.766	**buyinit**	0.119648	0.029659	4.034
qatask	-0.191843	0.080167	-2.393	**qatask**	-0.071173	0.038950	-1.827
qatbid	0.779376	0.067763	11.501	**qatbid**	0.189712	0.042354	4.479
qatask2	-0.000652	0.011079	-0.059	**qatask2**	0.007787	0.006972	1.117
qatbid2	-0.015118	0.007568	-1.998	**qatbid2**	0.007154	0.006894	1.038
askshock	0.158403	0.077495	2.044	**askshock**	0.045869	0.037738	1.215
bidshock	-0.629036	0.065616	-9.587	**bidshock**	-0.191769	0.041069	-4.669
sigmarun	-0.002291	0.009436	-0.243	**sigmarun**	-0.006162	0.007208	-0.855
Q3				**Q3**			
L1	0.247985	0.023314	10.637	**L1**	0.304335	0.007548	40.323
L2	0.251472	0.023370	10.760	**L2**	0.377578	0.007876	47.940
L3	-0.024193	0.023882	-1.013	**L3**	-0.020625	0.008260	-2.497
L4	0.112233	0.023624	4.751	**L4**	0.146228	0.008258	17.707
L5	-0.050412	0.022971	-2.195	**L5**	-0.007177	0.007874	-0.912
L6	0.137189	0.022446	6.112	**L6**	0.079292	0.007538	10.519
_cons	-0.024471	0.045704	-0.535	**_cons**	-0.031850	0.020073	-1.587

Q4				**Q4**			
buyinit	-0.036033	0.068300	-0.528	**buyinit**	-0.013151	0.033469	-0.393
qatask	-0.029121	0.085502	-0.341	**qatask**	-0.000858	0.043806	-0.020
qatbid	0.098909	0.073277	1.350	**qatbid**	0.030522	0.047665	0.640
qatask2	-0.005224	0.012209	-0.428	**qatask2**	0.005008	0.007877	0.636
qatbid2	-0.008705	0.008331	-1.045	**qatbid2**	0.009673	0.007791	1.241
askshock	-0.008693	0.081907	-0.106	**askshock**	-0.010508	0.042459	-0.247
bidshock	-0.028390	0.071383	-0.398	**bidshock**	-0.047057	0.046169	-1.019
sigmarun	0.007147	0.010365	0.690	**sigmarun**	-0.006006	0.008143	-0.737
Q4				**Q4**			
L1	0.263403	0.023536	11.191	**L1**	0.277173	0.007589	36.525
L2	0.282639	0.024267	11.647	**L2**	0.363172	0.007819	46.446
L3	-0.057126	0.025012	-2.284	**L3**	0.006222	0.008203	0.758
L4	0.042754	0.025013	1.709	**L4**	0.121667	0.008201	14.835
L5	0.022041	0.024309	0.907	**L5**	-0.008389	0.007815	-1.073
L6	0.074628	0.023427	3.186	**L6**	0.065381	0.007587	8.617
_cons	0.027744	0.050566	0.549	**_cons**	0.014475	0.022608	0.640
Q5				**Q5**			
buyinit	0.022173	0.066539	0.333	**buyinit**	0.004713	0.031399	0.150
qatask	-0.009904	0.082890	-0.119	**qatask**	0.020669	0.041046	0.504
qatbid	-0.059803	0.071165	-0.840	**qatbid**	0.059886	0.044745	1.338
qatask2	0.019632	0.011892	1.651	**qatask2**	0.002086	0.007383	0.283
qatbid2	0.011350	0.008124	1.397	**qatbid2**	0.004335	0.007303	0.594
askshock	-0.103914	0.079638	-1.305	**askshock**	-0.041810	0.039779	-1.051
bidshock	0.003566	0.069425	0.051	**bidshock**	-0.057934	0.043327	-1.337
sigmarun	-0.010697	0.010109	-1.058	**sigmarun**	-0.000703	0.007632	-0.092
Q5				**Q5**			
L1	0.333266	0.023659	14.086	**L1**	0.316518	0.008099	39.079
L2	0.173471	0.024820	6.989	**L2**	0.380483	0.008477	44.883
L3	0.023044	0.025066	0.919	**L3**	0.003837	0.008992	0.427
L4	0.024318	0.025057	0.971	**L4**	0.070602	0.008993	7.851
L5	0.025323	0.024796	1.021	**L5**	0.031777	0.008475	3.749
L6	0.103279	0.023664	4.364	**L6**	0.009129	0.008096	1.128
_cons	-0.009475	0.049283	-0.192	**_cons**	0.015772	0.021189	0.744

BBG				GWT			
Equation	**Obs**	**R-sq**	**Chi2**	**Equation**	**Obs**	**R-sq**	**Chi2**
dbestbid	5496	0.389	4620	**dbestbid**	1562	0.368	1391
dbestask	5496	0.301	3774	**dbestask**	1562	0.345	1241
spread	5496	-0.014	5984	**spread**	1562	0.011	2134
QD1	5496	0.203	1620	**QD1**	1562	0.343	939
QD2	5496	0.085	588	**QD2**	1562	0.310	917
QD3	5496	0.210	1654	**QD3**	1562	0.522	2299
QD4	5496	0.120	816	**QD4**	1562	0.462	1459
QD5	5496	0.191	1317	**QD5**	1562	0.614	3204
Q1	5496	0.225	1938	**Q1**	1562	0.561	2138
Q2	5496	0.139	1115	**Q2**	1562	0.157	369
Q3	5496	0.121	825	**Q3**	1562	0.362	901
Q4	5496	0.209	1578	**Q4**	1562	0.122	268
Q5	5496	0.235	1793	**Q5**	1562	0.308	714
ind. Var	**Coef.**	**Std. Error**	**Z**	**ind. Var**	**Coef.**	**Std. Error**	**Z**
dbestbid				**dbestbid**			
buyinit	0.010192	0.001756	5.803	**buyinit**	0.001718	0.001291	1.330
qatask	0.005388	0.001899	2.837	**qatask**	0.006389	0.001494	4.276
qatbid	-0.004648	0.002289	-2.031	**qatbid**	-0.004142	0.001505	-2.753
qatask2	-0.000842	0.000411	-2.049	**qatask2**	0.000043	0.000333	0.129
qatbid2	0.000577	0.000474	1.217	**qatbid2**	0.000612	0.000345	1.777
askshock	0.006870	0.001871	3.672	**askshock**	-0.003552	0.001402	-2.534
bidshock	-0.008411	0.002210	-3.806	**bidshock**	-0.000289	0.001428	-0.202
sigmarun	0.000282	0.000463	0.609	**sigmarun**	-0.000262	0.000339	-0.773
dbestbid				**dbestbid**			
L1	-0.336884	0.009463	-35.599	**L1**	-0.391289	0.017721	-22.081
L2	-0.069214	0.009948	-6.957	**L2**	-0.129560	0.019005	-6.817
L3	-0.081356	0.009934	-8.189	**L3**	-0.160201	0.018737	-8.550
L4	-0.024831	0.009963	-2.492	**L4**	-0.113149	0.018691	-6.054
L5	-0.031688	0.009734	-3.255	**L5**	-0.074540	0.018059	-4.128
L6	-0.000633	0.007323	-0.086	**L6**	-0.009170	0.012491	-0.734
_cons	-0.004717	0.001087	-4.339	**_cons**	0.000062	0.000847	0.074
dbestask				**dbestask**			
buyinit	0.009435	0.001558	6.054	**buyinit**	0.002010	0.001240	1.621
qatask	0.000498	0.001684	0.296	**qatask**	0.004117	0.001437	2.865
qatbid	-0.002324	0.002044	-1.137	**qatbid**	-0.004140	0.001453	-2.850
qatask2	-0.000723	0.000367	-1.972	**qatask2**	0.000044	0.000320	0.136
qatbid2	0.000259	0.000423	0.613	**qatbid2**	0.000711	0.000332	2.141
askshock	0.010952	0.001658	6.604	**askshock**	-0.001269	0.001348	-0.942
bidshock	-0.007514	0.001975	-3.805	**bidshock**	-0.000177	0.001378	-0.129
sigmarun	0.000381	0.000413	0.922	**sigmarun**	-0.000335	0.000326	-1.026
dbestask				**dbestask**			
L1	-0.317387	0.009609	-33.029	**L1**	-0.388280	0.018221	-21.310
L2	-0.060964	0.010023	-6.082	**L2**	-0.121962	0.019620	-6.216
L3	-0.075929	0.010009	-7.586	**L3**	-0.156614	0.019281	-8.123
L4	-0.018875	0.010042	-1.880	**L4**	-0.109615	0.019243	-5.696
L5	-0.032258	0.009827	-3.283	**L5**	-0.070877	0.018605	-3.810
L6	-0.001423	0.007722	-0.184	**L6**	-0.010664	0.012931	-0.825
_cons	-0.005511	0.000972	-5.669	**_cons**	-0.000691	0.000821	-0.841

spread				**spread**			
buyinit	-0.001393	0.000922	-1.511	**buyinit**	0.000169	0.000634	0.267
qatask	-0.003452	0.001034	-3.339	**qatask**	-0.001871	0.000764	-2.448
qatbid	0.002139	0.001254	1.705	**qatbid**	0.000067	0.000774	0.086
qatask2	0.000124	0.000225	0.549	**qatask2**	0.000030	0.000171	0.177
qatbid2	-0.000297	0.000260	-1.144	**qatbid2**	0.000121	0.000177	0.681
askshock	0.002708	0.001018	2.661	**askshock**	0.001808	0.000718	2.520
bidshock	0.001055	0.001211	0.871	**bidshock**	-0.000022	0.000734	-0.029
sigmarun	0.000077	0.000254	0.303	**sigmarun**	-0.000095	0.000174	-0.544
spread				**spread**			
L1	0.502965	0.009885	50.882	**L1**	0.512617	0.018481	27.738
L2	0.229846	0.010826	21.231	**L2**	0.236748	0.020225	11.706
L3	-0.009179	0.011013	-0.833	**L3**	-0.031686	0.020684	-1.532
L4	0.047280	0.010989	4.302	**L4**	0.036362	0.020485	1.775
L5	0.000856	0.010800	0.079	**L5**	0.043542	0.020084	2.168
L6	0.031250	0.010104	3.093	**L6**	0.046447	0.018496	2.511
_cons	0.003301	0.000642	5.143	**_cons**	0.001341	0.000506	2.652
QD1				**QD1**			
buyinit	-0.180532	0.051883	-3.480	**buyinit**	-0.265635	0.091382	-2.907
qatask	-0.076209	0.057581	-1.323	**qatask**	-0.061705	0.105200	-0.587
qatbid	0.248502	0.070751	3.512	**qatbid**	0.131721	0.107877	1.221
qatask2	0.017854	0.012588	1.418	**qatask2**	0.045194	0.023812	1.898
qatbid2	0.013685	0.014508	0.943	**qatbid2**	0.046818	0.024688	1.896
askshock	-0.015488	0.056683	-0.273	**askshock**	-0.020634	0.098624	-0.209
bidshock	-0.329621	0.068404	-4.819	**bidshock**	-0.172779	0.102524	-1.685
sigmarun	-0.011830	0.014187	-0.834	**sigmarun**	-0.053697	0.024242	-2.215
QD1				**QD1**			
L1	0.330311	0.013107	25.201	**L1**	0.393393	0.024309	16.183
L2	0.148741	0.013738	10.827	**L2**	0.236847	0.025915	9.140
L3	0.008072	0.013753	0.587	**L3**	-0.022431	0.026497	-0.847
L4	0.079668	0.013850	5.752	**L4**	0.080270	0.026482	3.031
L5	-0.036391	0.013731	-2.650	**L5**	-0.023626	0.026033	-0.908
L6	0.055620	0.013079	4.253	**L6**	0.041682	0.024518	1.700
_cons	0.157520	0.032988	4.775	**_cons**	0.165677	0.060592	2.734
QD2				**QD2**			
buyinit	0.067423	0.054838	1.229	**buyinit**	-0.000574	0.090338	-0.006
qatask	-0.001993	0.061457	-0.032	**qatask**	0.025360	0.107752	0.235
qatbid	0.106935	0.075119	1.424	**qatbid**	-0.004414	0.109948	-0.040
qatask2	-0.016014	0.013481	-1.188	**qatask2**	-0.067087	0.024477	-2.741
qatbid2	-0.014527	0.015535	-0.935	**qatbid2**	-0.088334	0.025377	-3.481
askshock	0.049304	0.060481	0.815	**askshock**	-0.009040	0.100915	-0.090
bidshock	-0.131542	0.072507	-1.814	**bidshock**	0.100121	0.104388	0.959
sigmarun	0.015777	0.015191	1.039	**sigmarun**	0.092934	0.024924	3.729
QD2				**QD2**			
L1	0.239639	0.013330	17.977	**L1**	0.421405	0.022354	18.851
L2	0.122787	0.013636	9.004	**L2**	0.156964	0.024254	6.472
L3	-0.003357	0.013730	-0.244	**L3**	-0.109415	0.024381	-4.488
L4	0.044090	0.013716	3.215	**L4**	0.106029	0.024316	4.360
L5	-0.012752	0.013637	-0.935	**L5**	0.033457	0.024406	1.371
L6	0.025902	0.013321	1.944	**L6**	0.132717	0.022417	5.920
_cons	-0.007055	0.035061	-0.201	**_cons**	0.002582	0.060787	0.042

QD3				**QD3**			
buyinit	0.070073	0.050906	1.377	**buyinit**	0.006632	0.075299	0.088
qatask	0.028976	0.057067	0.508	**qatask**	-0.068739	0.089498	-0.768
qatbid	0.087612	0.069606	1.259	**qatbid**	-0.017321	0.091456	-0.189
qatask2	0.004077	0.012590	0.324	**qatask2**	0.001261	0.020273	0.062
qatbid2	0.004001	0.014545	0.275	**qatbid2**	-0.009988	0.021004	-0.476
askshock	-0.008683	0.056199	-0.154	**askshock**	0.008807	0.083798	0.105
bidshock	-0.097462	0.067271	-1.449	**bidshock**	0.020650	0.086692	0.238
sigmarun	-0.004964	0.014193	-0.350	**sigmarun**	0.013906	0.020640	0.674
QD3				**QD3**			
L1	0.370012	0.013135	28.170	**L1**	0.407950	0.022199	18.377
L2	0.201048	0.013955	14.407	**L2**	0.286937	0.024094	11.909
L3	-0.020991	0.014166	-1.482	**L3**	-0.089595	0.024719	-3.624
L4	-0.072319	0.014148	-5.112	**L4**	0.124386	0.024644	5.047
L5	-0.005702	0.014004	-0.407	**L5**	0.067977	0.024147	2.815
L6	0.071670	0.013246	5.411	**L6**	0.072176	0.022267	3.241
_cons	-0.010417	0.032552	-0.320	**_cons**	-0.021227	0.050525	-0.420
QD4				**QD4**			
buyinit	0.043625	0.053757	0.812	**buyinit**	-0.121411	0.080015	-1.517
qatask	-0.057306	0.060185	-0.952	**qatask**	-0.045547	0.095927	-0.475
qatbid	0.065550	0.073492	0.892	**qatbid**	-0.155481	0.097963	-1.587
qatask2	-0.005407	0.013216	-0.409	**qatask2**	-0.004874	0.021610	-0.226
qatbid2	-0.011378	0.015230	-0.747	**qatbid2**	0.018370	0.022386	0.821
askshock	0.059777	0.059236	1.009	**askshock**	0.093961	0.089626	1.048
bidshock	-0.046139	0.070972	-0.650	**bidshock**	0.104351	0.092514	1.128
sigmarun	0.009941	0.014892	0.668	**sigmarun**	-0.008494	0.021971	-0.387
QD4				**QD4**			
L1	0.193540	0.013337	14.512	**L1**	0.352347	0.023276	15.138
L2	0.240079	0.013562	17.702	**L2**	0.224255	0.024605	9.114
L3	-0.028978	0.013916	-2.082	**L3**	-0.002110	0.025149	-0.084
L4	0.044135	0.013918	3.171	**L4**	0.016909	0.025170	0.672
L5	0.008200	0.013571	0.604	**L5**	0.059415	0.024565	2.419
L6	0.037228	0.013343	2.790	**L6**	0.167269	0.023123	7.234
_cons	-0.023264	0.034355	-0.677	**_cons**	0.010556	0.053917	0.196
QD5				**QD5**			
buyinit	-0.008175	0.051551	-0.159	**buyinit**	-0.042589	0.067550	-0.630
qatask	0.095207	0.057713	1.650	**qatask**	0.000714	0.081184	0.009
qatbid	0.065818	0.070585	0.932	**qatbid**	-0.048151	0.082691	-0.582
qatask2	0.042226	0.012671	3.332	**qatask2**	0.015081	0.018270	0.825
qatbid2	0.053456	0.014602	3.661	**qatbid2**	0.045151	0.018913	2.387
askshock	-0.076785	0.056792	-1.352	**askshock**	0.052789	0.075848	0.696
bidshock	-0.146453	0.068154	-2.149	**bidshock**	-0.031535	0.078261	-0.403
sigmarun	-0.052036	0.014279	-3.644	**sigmarun**	-0.042196	0.018574	-2.272
QD5				**QD5**			
L1	0.458025	0.013364	34.274	**L1**	0.432506	0.021907	19.743
L2	-0.115326	0.014682	-7.855	**L2**	0.225592	0.024157	9.338
L3	0.077206	0.014778	5.225	**L3**	0.033725	0.024560	1.373
L4	-0.010550	0.014773	-0.714	**L4**	0.108318	0.024481	4.425
L5	0.011208	0.014682	0.763	**L5**	-0.044420	0.024186	-1.837
L6	0.016837	0.013333	1.263	**L6**	0.138756	0.021912	6.332
_cons	0.036975	0.032950	1.122	**_cons**	0.016226	0.045621	0.356

Q1				**Q1**			
buyinit	0.161144	0.050734	3.176	**buyinit**	0.097736	0.072537	1.347
qatask	-0.015240	0.057479	-0.265	**qatask**	-0.118318	0.086369	-1.370
qatbid	0.249309	0.070141	3.554	**qatbid**	-0.058645	0.088347	-0.664
qatask2	0.025849	0.012410	2.083	**qatask2**	0.045423	0.019510	2.328
qatbid2	0.025281	0.014298	1.768	**qatbid2**	0.047255	0.020226	2.336
askshock	-0.018271	0.056454	-0.324	**askshock**	0.028646	0.080935	0.354
bidshock	-0.270834	0.067637	-4.004	**bidshock**	-0.003929	0.083665	-0.047
sigmarun	-0.028716	0.013981	-2.054	**sigmarun**	-0.047487	0.019876	-2.389
Q1				**Q1**			
L1	0.241004	0.013122	18.367	**L1**	0.325200	0.024837	13.093
L2	0.259787	0.013361	19.443	**L2**	0.368651	0.026039	14.158
L3	0.025646	0.013771	1.862	**L3**	-0.001838	0.027658	-0.066
L4	0.083364	0.013758	6.059	**L4**	0.088580	0.027889	3.176
L5	0.019500	0.013419	1.453	**L5**	0.071645	0.026511	2.702
L6	0.067385	0.013125	5.134	**L6**	0.025728	0.025920	0.993
_cons	-0.020568	0.032620	-0.631	**_cons**	-0.078806	0.048752	-1.616
Q2				**Q2**			
buyinit	-0.004507	0.053191	-0.085	**buyinit**	-0.082984	0.099952	-0.830
qatask	0.192325	0.060001	3.205	**qatask**	-0.072163	0.119268	-0.605
qatbid	0.140647	0.073478	1.914	**qatbid**	0.016147	0.122066	0.132
qatask2	0.001498	0.013072	0.115	**qatask2**	-0.012936	0.027013	-0.479
qatbid2	0.009730	0.015063	0.646	**qatbid2**	0.010055	0.028004	0.359
askshock	-0.180359	0.058969	-3.059	**askshock**	0.107515	0.111772	0.962
bidshock	-0.134161	0.070921	-1.892	**bidshock**	-0.042765	0.115675	-0.370
sigmarun	-0.008621	0.014730	-0.585	**sigmarun**	0.009726	0.027502	0.354
Q2				**Q2**			
L1	0.189954	0.013082	14.520	**L1**	0.171290	0.023252	7.367
L2	0.244674	0.013180	18.564	**L2**	0.238047	0.023674	10.055
L3	-0.014740	0.013494	-1.092	**L3**	0.095213	0.024198	3.935
L4	0.074308	0.013494	5.507	**L4**	0.071748	0.024227	2.962
L5	0.016844	0.013150	1.281	**L5**	-0.045882	0.023689	-1.937
L6	0.074547	0.012991	5.738	**L6**	0.032094	0.023384	1.372
_cons	0.079392	0.034126	2.326	**_cons**	0.013753	0.067234	0.205
Q3				**Q3**			
buyinit	-0.117407	0.053883	-2.179	**buyinit**	-0.125504	0.087028	-1.442
qatask	0.377163	0.061072	6.176	**qatask**	0.277032	0.103955	2.665
qatbid	0.156545	0.074956	2.088	**qatbid**	0.118402	0.105966	1.117
qatask2	-0.001104	0.013218	-0.084	**qatask2**	-0.032134	0.023537	-1.365
qatbid2	0.001206	0.015235	0.079	**qatbid2**	-0.028224	0.024421	-1.156
askshock	-0.365044	0.059983	-6.086	**askshock**	-0.217228	0.097401	-2.230
bidshock	-0.145359	0.072308	-2.010	**bidshock**	-0.051634	0.100585	-0.513
sigmarun	-0.000697	0.014898	-0.047	**sigmarun**	0.018810	0.023976	0.785
Q3				**Q3**			
L1	0.188911	0.013329	14.173	**L1**	0.350847	0.024784	14.156
L2	0.178732	0.013524	13.216	**L2**	0.114901	0.026139	4.396
L3	0.033521	0.013704	2.446	**L3**	0.175159	0.026286	6.664
L4	0.026233	0.013699	1.915	**L4**	0.033452	0.026291	1.272
L5	0.040283	0.013507	2.982	**L5**	0.085360	0.026145	3.265
L6	0.029847	0.013334	2.238	**L6**	-0.025413	0.024832	-1.023
_cons	0.183444	0.034652	5.294	**_cons**	0.164605	0.058605	2.809

Q4				**Q4**			
buyinit	0.055580	0.051038	1.089	**buyinit**	-0.029267	0.101688	-0.288
qatask	0.175714	0.057586	3.051	**qatask**	0.013512	0.121328	0.111
qatbid	0.183908	0.070609	2.605	**qatbid**	0.021696	0.123905	0.175
qatask2	0.005308	0.012533	0.424	**qatask2**	0.001591	0.027490	0.058
qatbid2	0.009436	0.014449	0.653	**qatbid2**	0.008942	0.028482	0.314
askshock	-0.206841	0.056609	-3.654	**askshock**	0.017732	0.113704	0.156
bidshock	-0.187625	0.068011	-2.759	**bidshock**	0.036682	0.117674	0.312
sigmarun	-0.006381	0.014125	-0.452	**sigmarun**	-0.009243	0.027995	-0.330
Q4				**Q4**			
L1	0.234916	0.013336	17.616	**L1**	0.182467	0.023699	7.699
L2	0.181122	0.013670	13.249	**L2**	0.141638	0.023979	5.907
L3	0.067752	0.013682	4.952	**L3**	0.053107	0.024032	2.210
L4	0.157745	0.013672	11.538	**L4**	0.119156	0.024128	4.938
L5	-0.029495	0.013664	-2.159	**L5**	0.041706	0.023947	1.742
L6	0.019405	0.013319	1.457	**L6**	0.039714	0.023670	1.678
_cons	0.061732	0.032715	1.887	**_cons**	0.001184	0.068475	0.017
Q5				**Q5**			
buyinit	0.028493	0.050195	0.568	**buyinit**	0.186908	0.090622	2.062
qatask	0.173455	0.056396	3.076	**qatask**	0.070087	0.108278	0.647
qatbid	0.136820	0.069104	1.980	**qatbid**	0.458790	0.110681	4.145
qatask2	0.003177	0.012327	0.258	**qatask2**	0.005665	0.024480	0.231
qatbid2	0.002300	0.014209	0.162	**qatbid2**	-0.014412	0.025364	-0.568
askshock	-0.188996	0.055467	-3.407	**askshock**	-0.118149	0.101514	-1.164
bidshock	-0.129448	0.066675	-1.941	**bidshock**	-0.403886	0.105059	-3.844
sigmarun	-0.003734	0.013892	-0.269	**sigmarun**	-0.001606	0.024926	-0.064
Q5				**Q5**			
L1	0.214125	0.013278	16.126	**L1**	0.280442	0.024636	11.384
L2	0.266792	0.013550	19.690	**L2**	0.127946	0.025588	5.000
L3	0.012980	0.013945	0.931	**L3**	-0.017011	0.024700	-0.689
L4	0.096495	0.013951	6.917	**L4**	0.301575	0.024706	12.206
L5	0.020062	0.013547	1.481	**L5**	-0.030368	0.025514	-1.190
L6	0.056619	0.013271	4.266	**L6**	0.039001	0.024599	1.585
_cons	0.062568	0.032105	1.949	**_cons**	0.044608	0.061021	0.731

MBL				NWS			
Equation	**Obs**	**R-sq**	**Chi2**	**Equation**	**Obs**	**R-sq**	**Chi2**
dbestbid	26083	0.324	18002	**dbestbid**	9256	0.294	6252
dbestask	26083	0.244	14567	**dbestask**	9256	0.237	5388
spread	26083	0.100	45867	**spread**	9256	0.054	13393
QD1	26083	0.149	5135	**QD1**	9256	0.273	4062
QD2	26083	0.152	5772	**QD2**	9256	0.200	2913
QD3	26083	0.167	6368	**QD3**	9256	0.238	3602
QD4	26083	0.179	6275	**QD4**	9256	0.198	2786
QD5	26083	0.122	3957	**QD5**	9256	0.187	2348
Q1	26083	0.207	8601	**Q1**	9256	0.402	6584
Q2	26083	0.188	6798	**Q2**	9256	0.168	2293
Q3	26083	0.157	5768	**Q3**	9256	0.299	4901
Q4	26083	0.155	5746	**Q4**	9256	0.285	4972
Q5	26083	0.153	5083	**Q5**	9256	0.294	5042
ind. Var	**Coef.**	**Std. Error**	**Z**	**ind. Var**	**Coef.**	**Std. Error**	**Z**
dbestbid				**dbestbid**			
buyinit	0.005167	0.001378	3.749	**buyinit**	0.006364	0.001257	5.062
qatask	0.022124	0.001941	11.400	**qatask**	0.003222	0.001429	2.255
qatbid	-0.012042	0.002091	-5.759	**qatbid**	-0.003181	0.001219	-2.610
qatask2	-0.001572	0.000475	-3.306	**qatask2**	-0.000417	0.000204	-2.047
qatbid2	-0.000326	0.000478	-0.682	**qatbid2**	0.000426	0.000139	3.064
askshock	-0.006430	0.001883	-3.415	**askshock**	0.004117	0.001374	2.997
bidshock	-0.001634	0.002071	-0.789	**bidshock**	-0.002122	0.001190	-1.783
sigmarun	0.000789	0.000481	1.641	**sigmarun**	-0.000276	0.000173	-1.597
dbestbid				**dbestbid**			
L1	-0.303842	0.004405	-68.979	**L1**	-0.390344	0.016991	-22.973
L2	-0.009893	0.004645	-2.130	**L2**	-0.136145	0.018213	-7.475
L3	-0.042830	0.004610	-9.292	**L3**	-0.162378	0.018137	-8.953
L4	0.000438	0.004659	0.094	**L4**	-0.069260	0.018195	-3.807
L5	-0.026566	0.004563	-5.821	**L5**	-0.053174	0.017540	-3.032
L6	0.014641	0.003387	4.323	**L6**	-0.003616	0.012046	-0.300
_cons	-0.000373	0.000974	-0.383	**_cons**	-0.002871	0.000880	-3.264
dbestask				**dbestask**			
buyinit	0.001662	0.001351	1.230	**buyinit**	0.005342	0.001240	4.307
qatask	0.015646	0.001911	8.189	**qatask**	0.002687	0.001431	1.878
qatbid	-0.015592	0.002065	-7.551	**qatbid**	-0.001662	0.001224	-1.358
qatask2	-0.002377	0.000469	-5.070	**qatask2**	-0.000657	0.000205	-3.212
qatbid2	-0.001255	0.000471	-2.664	**qatbid2**	0.000288	0.000140	2.062
askshock	0.001469	0.001854	0.792	**askshock**	0.005128	0.001374	3.731
bidshock	0.004863	0.002046	2.377	**bidshock**	-0.003438	0.001194	-2.879
sigmarun	0.001626	0.000474	3.429	**sigmarun**	-0.000101	0.000174	-0.581
dbestask				**dbestask**			
L1	-0.301335	0.004452	-67.685	**L1**	-0.388881	0.017266	-22.522
L2	-0.012330	0.004682	-2.634	**L2**	-0.135747	0.018468	-7.351
L3	-0.043726	0.004639	-9.426	**L3**	-0.162514	0.018394	-8.835
L4	0.002681	0.004690	0.572	**L4**	-0.069318	0.018445	-3.758
L5	-0.025313	0.004590	-5.514	**L5**	-0.051981	0.017770	-2.925
L6	0.016047	0.003421	4.690	**L6**	-0.002882	0.012157	-0.237
_cons	-0.001417	0.000960	-1.476	**_cons**	-0.002147	0.000876	-2.449

spread				**spread**			
buyinit	-0.003965	0.000715	-5.549	**buyinit**	-0.001054	0.000633	-1.665
qatask	-0.003173	0.001031	-3.078	**qatask**	-0.000536	0.000788	-0.680
qatbid	-0.001650	0.001098	-1.503	**qatbid**	0.001335	0.000673	1.983
qatask2	-0.000641	0.000253	-2.530	**qatask2**	-0.000227	0.000113	-2.011
qatbid2	-0.000764	0.000254	-3.004	**qatbid2**	-0.000129	0.000077	-1.680
askshock	0.004388	0.001000	4.389	**askshock**	0.000951	0.000755	1.260
bidshock	0.004418	0.001084	4.075	**bidshock**	-0.001193	0.000657	-1.816
sigmarun	0.000674	0.000256	2.631	**sigmarun**	0.000170	0.000096	1.773
spread				**spread**			
L1	0.549764	0.004572	120.236	**L1**	0.518768	0.017531	29.591
L2	0.273797	0.005086	53.832	**L2**	0.220626	0.019576	11.270
L3	-0.018147	0.005201	-3.489	**L3**	-0.021950	0.019746	-1.112
L4	0.048890	0.005188	9.424	**L4**	0.077151	0.019744	3.908
L5	-0.015760	0.005048	-3.122	**L5**	0.014069	0.019497	0.722
L6	0.037077	0.004666	7.946	**L6**	0.045661	0.017825	2.562
_cons	0.003663	0.000541	6.771	**_cons**	0.002743	0.000553	4.963
QD1				**QD1**			
buyinit	-0.284819	0.029675	-9.598	**buyinit**	-0.239266	0.063264	-3.782
qatask	0.094183	0.042274	2.228	**qatask**	-0.121829	0.080813	-1.508
qatbid	0.286791	0.045523	6.300	**qatbid**	0.225016	0.069320	3.246
qatask2	-0.027476	0.010390	-2.645	**qatask2**	-0.004308	0.011211	-0.384
qatbid2	-0.027449	0.010441	-2.629	**qatbid2**	-0.005465	0.007713	-0.709
askshock	-0.057886	0.040942	-1.414	**askshock**	-0.006065	0.077226	-0.079
bidshock	-0.286162	0.044856	-6.380	**bidshock**	-0.230293	0.066591	-3.458
sigmarun	0.026902	0.010509	2.560	**sigmarun**	0.015377	0.009564	1.608
QD1				**QD1**			
L1	0.266822	0.006107	43.690	**L1**	0.374424	0.023802	15.731
L2	0.150380	0.006307	23.845	**L2**	0.225527	0.025671	8.785
L3	0.002160	0.006342	0.341	**L3**	0.008631	0.025923	0.333
L4	0.046765	0.006340	7.377	**L4**	0.027596	0.026061	1.059
L5	0.012362	0.006280	1.969	**L5**	-0.006378	0.025364	-0.251
L6	0.045871	0.006096	7.524	**L6**	0.045764	0.023857	1.918
_cons	0.238901	0.021374	11.177	**_cons**	0.157240	0.046509	3.381
QD2				**QD2**			
buyinit	-0.026818	0.029261	-0.916	**buyinit**	-0.059515	0.071616	-0.831
qatask	0.010289	0.042115	0.244	**qatask**	-0.009210	0.089224	-0.103
qatbid	0.126664	0.045096	2.809	**qatbid**	0.221198	0.076563	2.889
qatask2	-0.017968	0.010386	-1.730	**qatask2**	0.002331	0.012784	0.182
qatbid2	-0.020283	0.010437	-1.943	**qatbid2**	-0.016173	0.008746	-1.849
askshock	-0.005923	0.040814	-0.145	**askshock**	-0.029025	0.085535	-0.339
bidshock	-0.150760	0.044477	-3.390	**bidshock**	-0.094734	0.074462	-1.272
sigmarun	0.020606	0.010505	1.962	**sigmarun**	0.007352	0.010884	0.675
QD2				**QD2**			
L1	0.294607	0.006046	48.724	**L1**	0.221084	0.023692	9.332
L2	0.158316	0.006252	25.321	**L2**	0.187875	0.024097	7.797
L3	0.036537	0.006312	5.789	**L3**	0.049069	0.024418	2.010
L4	0.074271	0.006306	11.778	**L4**	0.024965	0.024509	1.019
L5	0.000570	0.006256	0.091	**L5**	0.048831	0.024083	2.028
L6	0.007874	0.006042	1.303	**L6**	0.014953	0.023886	0.626
_cons	0.058191	0.021192	2.746	**_cons**	0.058616	0.052988	1.106

QD3				**QD3**			
buyinit	-0.006873	0.029002	-0.237	**buyinit**	0.176996	0.066321	2.669
qatask	-0.022058	0.041731	-0.529	**qatask**	-0.183253	0.083937	-2.183
qatbid	0.039378	0.044632	0.882	**qatbid**	0.489185	0.071639	6.829
qatask2	0.009013	0.010302	0.875	**qatask2**	-0.008968	0.011955	-0.750
qatbid2	0.006778	0.010352	0.655	**qatbid2**	-0.016009	0.008139	-1.967
askshock	-0.003552	0.040444	-0.088	**askshock**	0.096976	0.081091	1.196
bidshock	-0.069566	0.044020	-1.580	**bidshock**	-0.510449	0.069744	-7.319
sigmarun	-0.007287	0.010420	-0.699	**sigmarun**	0.019737	0.010179	1.939
QD3				**QD3**			
L1	0.304864	0.006034	50.529	**L1**	0.204976	0.023607	8.683
L2	0.152662	0.006275	24.329	**L2**	0.351898	0.023380	15.052
L3	0.067524	0.006328	10.670	**L3**	0.015573	0.024859	0.626
L4	0.037921	0.006325	5.996	**L4**	0.047306	0.024745	1.912
L5	-0.002821	0.006278	-0.449	**L5**	-0.009248	0.023345	-0.396
L6	0.041389	0.006034	6.859	**L6**	0.000025	0.022943	0.001
_cons	0.018078	0.020998	0.861	**_cons**	-0.001726	0.049122	-0.035
QD4				**QD4**			
buyinit	0.025542	0.028763	0.888	**buyinit**	-0.031482	0.065285	-0.482
qatask	-0.022927	0.041423	-0.553	**qatask**	-0.008905	0.081283	-0.110
qatbid	0.081713	0.044208	1.848	**qatbid**	0.030054	0.069559	0.432
qatask2	-0.008601	0.010226	-0.841	**qatask2**	0.001154	0.011644	0.099
qatbid2	-0.010636	0.010276	-1.035	**qatbid2**	0.000465	0.007949	0.059
askshock	0.017607	0.040142	0.439	**askshock**	-0.014012	0.078031	-0.180
bidshock	-0.094895	0.043629	-2.175	**bidshock**	-0.044061	0.067855	-0.649
sigmarun	0.011218	0.010343	1.085	**sigmarun**	0.000168	0.009889	0.017
QD4				**QD4**			
L1	0.270115	0.006133	44.042	**L1**	0.390082	0.023702	16.458
L2	0.184108	0.006332	29.074	**L2**	0.213579	0.025358	8.422
L3	0.038001	0.006420	5.919	**L3**	-0.047055	0.025706	-1.831
L4	0.057316	0.006420	8.928	**L4**	0.089344	0.025733	3.472
L5	0.031203	0.006335	4.925	**L5**	-0.003885	0.025460	-0.153
L6	0.038636	0.006134	6.298	**L6**	0.056259	0.023786	2.365
_cons	0.009439	0.020844	0.453	**_cons**	0.028175	0.048328	0.583
QD5				**QD5**			
buyinit	-0.008360	0.029762	-0.281	**buyinit**	-0.146703	0.060420	-2.428
qatask	0.024648	0.042873	0.575	**qatask**	0.229498	0.075517	3.039
qatbid	0.031041	0.045779	0.678	**qatbid**	-0.243358	0.065062	-3.740
qatask2	-0.004426	0.010580	-0.418	**qatask2**	0.049968	0.010781	4.635
qatbid2	-0.001348	0.010632	-0.127	**qatbid2**	0.039834	0.007371	5.404
askshock	-0.025282	0.041549	-0.608	**askshock**	-0.314300	0.072565	-4.331
bidshock	-0.061180	0.045173	-1.354	**bidshock**	0.254648	0.063157	4.032
sigmarun	0.005160	0.010701	0.482	**sigmarun**	-0.047478	0.009184	-5.170
QD5				**QD5**			
L1	0.225541	0.006135	36.766	**L1**	0.345262	0.023585	14.639
L2	0.171689	0.006278	27.349	**L2**	0.305881	0.024802	12.333
L3	0.009378	0.006352	1.477	**L3**	-0.072498	0.025535	-2.839
L4	0.063682	0.006350	10.029	**L4**	0.131975	0.025623	5.151
L5	0.022204	0.006281	3.535	**L5**	0.036722	0.024441	1.502
L6	0.041241	0.006134	6.724	**L6**	0.017251	0.023609	0.731
_cons	0.024065	0.021572	1.116	**_cons**	0.057706	0.044500	1.297

Q1				**Q1**			
buyinit	0.042884	0.028384	1.511	**buyinit**	0.161665	0.062441	2.589
qatask	0.159181	0.041304	3.854	**qatask**	0.002836	0.079410	0.036
qatbid	0.132758	0.043524	3.050	**qatbid**	0.405757	0.068146	5.954
qatask2	-0.022657	0.010022	-2.261	**qatask2**	-0.014251	0.011057	-1.289
qatbid2	-0.017142	0.010072	-1.702	**qatbid2**	-0.021491	0.007562	-2.842
askshock	-0.102731	0.039979	-2.570	**askshock**	0.054776	0.076368	0.717
bidshock	-0.064190	0.042950	-1.495	**bidshock**	-0.133109	0.065838	-2.022
sigmarun	0.021046	0.010137	2.076	**sigmarun**	0.009109	0.009408	0.968
Q1				**Q1**			
L1	0.270580	0.006041	44.795	**L1**	0.133760	0.023676	5.650
L2	0.209113	0.006179	33.842	**L2**	0.564566	0.023934	23.588
L3	0.027363	0.006270	4.364	**L3**	-0.015557	0.026827	-0.580
L4	0.110693	0.006256	17.695	**L4**	-0.187177	0.026968	-6.941
L5	0.038250	0.006184	6.185	**L5**	0.044304	0.023763	1.864
L6	0.020977	0.006005	3.493	**L6**	0.104664	0.023698	4.417
_cons	0.026215	0.020772	1.262	**_cons**	-0.037377	0.046314	-0.807
Q2				**Q2**			
buyinit	0.016604	0.028638	0.580	**buyinit**	-0.147545	0.062916	-2.345
qatask	0.114941	0.041249	2.787	**qatask**	0.358404	0.080726	4.440
qatbid	0.118269	0.043972	2.690	**qatbid**	-0.057004	0.069177	-0.824
qatask2	-0.027610	0.010177	-2.713	**qatask2**	0.038449	0.011192	3.436
qatbid2	-0.024337	0.010227	-2.380	**qatbid2**	0.041962	0.007655	5.482
askshock	-0.078369	0.039971	-1.961	**askshock**	-0.416482	0.077195	-5.395
bidshock	-0.114626	0.043400	-2.641	**bidshock**	-0.026133	0.066808	-0.391
sigmarun	0.026806	0.010293	2.604	**sigmarun**	-0.040692	0.009536	-4.267
Q2				**Q2**			
L1	0.391463	0.006076	64.426	**L1**	0.303126	0.023656	12.814
L2	0.130746	0.006499	20.118	**L2**	0.233661	0.024811	9.418
L3	-0.069562	0.006542	-10.633	**L3**	0.010976	0.025267	0.434
L4	0.020589	0.006542	3.147	**L4**	-0.000785	0.025954	-0.030
L5	0.020791	0.006500	3.199	**L5**	0.014547	0.025492	0.571
L6	0.021961	0.006075	3.615	**L6**	0.112665	0.024868	4.530
_cons	0.047535	0.020759	2.290	**_cons**	0.136301	0.046976	2.902
Q3				**Q3**			
buyinit	-0.069817	0.029147	-2.395	**buyinit**	0.294289	0.061743	4.766
qatask	0.097938	0.041966	2.334	**qatask**	-0.191843	0.080167	-2.393
qatbid	-0.066429	0.044770	-1.484	**qatbid**	0.779376	0.067763	11.501
qatask2	0.026582	0.010362	2.565	**qatask2**	-0.000652	0.011079	-0.059
qatbid2	0.029589	0.010413	2.842	**qatbid2**	-0.015118	0.007568	-1.998
askshock	-0.123835	0.040673	-3.045	**askshock**	0.158403	0.077495	2.044
bidshock	0.019580	0.044188	0.443	**bidshock**	-0.629036	0.065616	-9.587
sigmarun	-0.028120	0.010481	-2.683	**sigmarun**	-0.002291	0.009436	-0.243
Q3				**Q3**			
L1	0.319182	0.006080	52.494	**L1**	0.247985	0.023314	10.637
L2	0.172764	0.006354	27.190	**L2**	0.251472	0.023370	10.760
L3	-0.019075	0.006433	-2.965	**L3**	-0.024193	0.023882	-1.013
L4	0.024361	0.006433	3.787	**L4**	0.112233	0.023624	4.751
L5	0.031245	0.006356	4.916	**L5**	-0.050412	0.022971	-2.195
L6	0.022753	0.006083	3.740	**L6**	0.137189	0.022446	6.112
_cons	0.047747	0.021118	2.261	**_cons**	-0.024471	0.045704	-0.535

Q4				**Q4**			
buyinit	-0.008592	0.029171	-0.295	**buyinit**	-0.036033	0.068300	-0.528
qatask	0.059057	0.041995	1.406	**qatask**	-0.029121	0.085502	-0.341
qatbid	-0.026985	0.044806	-0.602	**qatbid**	0.098909	0.073277	1.350
qatask2	0.002472	0.010371	0.238	**qatask2**	-0.005224	0.012209	-0.428
qatbid2	0.006226	0.010421	0.597	**qatbid2**	-0.008705	0.008331	-1.045
askshock	-0.058466	0.040704	-1.436	**askshock**	-0.008693	0.081907	-0.106
bidshock	-0.008114	0.044224	-0.183	**bidshock**	-0.028390	0.071383	-0.398
sigmarun	-0.003906	0.010490	-0.372	**sigmarun**	0.007147	0.010365	0.690
Q4				**Q4**			
L1	0.314712	0.006071	51.837	**L1**	0.263403	0.023536	11.191
L2	0.136686	0.006341	21.557	**L2**	0.282639	0.024267	11.647
L3	0.021165	0.006374	3.320	**L3**	-0.057126	0.025012	-2.284
L4	0.044843	0.006374	7.036	**L4**	0.042754	0.025013	1.709
L5	0.016401	0.006339	2.587	**L5**	0.022041	0.024309	0.907
L6	0.052256	0.006070	8.609	**L6**	0.074628	0.023427	3.186
_cons	0.019050	0.021132	0.901	**_cons**	0.027744	0.050566	0.549
Q5				**Q5**			
buyinit	0.024852	0.029231	0.850	**buyinit**	0.022173	0.066539	0.333
qatask	0.056062	0.042104	1.331	**qatask**	-0.009904	0.082890	-0.119
qatbid	0.070309	0.044926	1.565	**qatbid**	-0.059803	0.071165	-0.840
qatask2	-0.026042	0.010392	-2.506	**qatask2**	0.019632	0.011892	1.651
qatbid2	-0.034315	0.010443	-3.286	**qatbid2**	0.011350	0.008124	1.397
askshock	-0.047223	0.040805	-1.157	**askshock**	-0.103914	0.079638	-1.305
bidshock	-0.043866	0.044333	-0.989	**bidshock**	0.003566	0.069425	0.051
sigmarun	0.034961	0.010511	3.326	**sigmarun**	-0.010697	0.010109	-1.058
Q5				**Q5**			
L1	0.242681	0.006117	39.676	**L1**	0.333266	0.023659	14.086
L2	0.167542	0.006287	26.650	**L2**	0.173471	0.024820	6.989
L3	0.062109	0.006361	9.765	**L3**	0.023044	0.025066	0.919
L4	0.052714	0.006359	8.289	**L4**	0.024318	0.025057	0.971
L5	0.000458	0.006288	0.073	**L5**	0.025323	0.024796	1.021
L6	0.051940	0.006117	8.492	**L6**	0.103279	0.023664	4.364
_cons	0.016167	0.021182	0.763	**_cons**	-0.009475	0.049283	-0.192

ZFX				QAN			
Equation	**Obs**	**R-sq**	**Chi2**	**Equation**	**Obs**	**R-sq**	**Chi2**
dbestbid	17246	0.301	11760	**dbestbid**	9170	0.429	9162
dbestask	17246	0.268	10820	**dbestask**	9170	0.420	9053
spread	17246	0.048	22397	**spread**	9170	-0.054	10076
QD1	17246	0.447	15675	**QD1**	9170	0.666	22032
QD2	17246	0.266	8024	**QD2**	9170	0.473	11124
QD3	17246	0.260	7321	**QD3**	9170	0.681	21191
QD4	17246	0.245	7678	**QD4**	9170	0.423	10667
QD5	17246	0.289	8357	**QD5**	9170	0.603	18521
Q1	17246	0.572	26639	**Q1**	9170	0.679	21028
Q2	17246	0.480	18663	**Q2**	9170	0.577	16173
Q3	17246	0.394	12626	**Q3**	9170	0.740	28729
Q4	17246	0.472	19341	**Q4**	9170	0.523	12286
Q5	17246	0.424	14265	**Q5**	9170	0.690	21344
ind. Var	**Coef.**	**Std. Error**	**Z**	**ind. Var**	**Coef.**	**Std. Error**	**Z**
dbestbid				**dbestbid**			
buyinit	0.003808	0.000638	5.967	**buyinit**	0.001615	0.000222	7.276
qatask	0.005050	0.000884	5.711	**qatask**	0.002377	0.000316	7.520
qatbid	-0.001656	0.000923	-1.795	**qatbid**	-0.002632	0.000339	-7.775
qatask2	-0.000749	0.000221	-3.387	**qatask2**	-0.000191	0.000048	-3.978
qatbid2	-0.000192	0.000218	-0.880	**qatbid2**	0.000159	0.000047	3.415
askshock	0.000939	0.000863	1.089	**askshock**	0.000324	0.000309	1.048
bidshock	-0.002718	0.000897	-3.029	**bidshock**	-0.000346	0.000333	-1.040
sigmarun	0.000396	0.000220	1.801	**sigmarun**	0.000014	0.000049	0.283
dbestbid				**dbestbid**			
L1	-0.290263	0.005407	-53.681	**L1**	-0.347843	0.006924	-50.236
L2	-0.007581	0.005654	-1.341	**L2**	-0.113487	0.007374	-15.390
L3	-0.060384	0.005633	-10.721	**L3**	-0.099497	0.007299	-13.631
L4	0.008748	0.005657	1.546	**L4**	-0.013253	0.007309	-1.813
L5	-0.019794	0.005547	-3.568	**L5**	-0.034374	0.007094	-4.846
L6	0.008886	0.004356	2.040	**L6**	-0.004107	0.005232	-0.785
_cons	-0.000972	0.000438	-2.219	**_cons**	-0.000881	0.000151	-5.852
dbestask				**dbestask**			
buyinit	0.003229	0.000636	5.075	**buyinit**	0.001341	0.000218	6.141
qatask	0.004185	0.000885	4.728	**qatask**	0.002791	0.000312	8.954
qatbid	-0.002359	0.000923	-2.556	**qatbid**	-0.002538	0.000334	-7.593
qatask2	-0.000935	0.000221	-4.233	**qatask2**	-0.000199	0.000047	-4.199
qatbid2	-0.000384	0.000218	-1.762	**qatbid2**	0.000148	0.000046	3.229
askshock	0.002115	0.000863	2.449	**askshock**	-0.000066	0.000305	-0.217
bidshock	-0.001518	0.000898	-1.691	**bidshock**	-0.000419	0.000329	-1.275
sigmarun	0.000579	0.000220	2.631	**sigmarun**	0.000024	0.000048	0.494
dbestask				**dbestask**			
L1	-0.290067	0.005386	-53.855	**L1**	-0.347429	0.006945	-50.023
L2	-0.008424	0.005633	-1.495	**L2**	-0.114113	0.007394	-15.434
L3	-0.059413	0.005611	-10.590	**L3**	-0.100241	0.007319	-13.696
L4	0.008435	0.005637	1.496	**L4**	-0.013444	0.007332	-1.834
L5	-0.019527	0.005521	-3.537	**L5**	-0.034508	0.007114	-4.851
L6	0.009351	0.004341	2.154	**L6**	-0.004392	0.005278	-0.832
_cons	-0.001132	0.000438	-2.584	**_cons**	-0.000654	0.000148	-4.423

spread				**spread**			
buyinit	-0.000566	0.000195	-2.903	**buyinit**	-0.000254	0.000054	-4.694
qatask	-0.000591	0.000277	-2.138	**qatask**	0.000303	0.000080	3.799
qatbid	-0.000528	0.000287	-1.842	**qatbid**	0.000048	0.000085	0.570
qatask2	-0.000189	0.000069	-2.728	**qatask2**	-0.000003	0.000012	-0.238
qatbid2	-0.000196	0.000068	-2.870	**qatbid2**	-0.000006	0.000012	-0.518
askshock	0.000885	0.000270	3.278	**askshock**	-0.000287	0.000078	-3.676
bidshock	0.001033	0.000278	3.716	**bidshock**	-0.000033	0.000083	-0.392
sigmarun	0.000187	0.000069	2.705	**sigmarun**	0.000005	0.000012	0.421
spread				**spread**			
L1	0.523688	0.005674	92.296	**L1**	0.527442	0.007514	70.192
L2	0.259990	0.006262	41.516	**L2**	0.175063	0.008217	21.305
L3	-0.034033	0.006386	-5.329	**L3**	0.022044	0.008252	2.671
L4	0.069318	0.006396	10.838	**L4**	0.072551	0.008215	8.832
L5	-0.012219	0.006263	-1.951	**L5**	-0.007392	0.008186	-0.903
L6	0.033272	0.005848	5.690	**L6**	0.015845	0.007562	2.095
_cons	0.001754	0.000155	11.327	**_cons**	0.002168	0.000113	19.248
QD1				**QD1**			
buyinit	-0.203157	0.032675	-6.217	**buyinit**	-0.080084	0.022002	-3.640
qatask	-0.074314	0.046616	-1.594	**qatask**	-0.045181	0.033107	-1.365
qatbid	0.191897	0.048383	3.966	**qatbid**	0.289071	0.034769	8.314
qatask2	0.010555	0.011577	0.912	**qatask2**	0.022244	0.004966	4.479
qatbid2	-0.008872	0.011404	-0.778	**qatbid2**	0.006517	0.004814	1.354
askshock	-0.013096	0.045434	-0.288	**askshock**	-0.109269	0.032351	-3.378
bidshock	-0.221885	0.046906	-4.730	**bidshock**	-0.304040	0.034245	-8.878
sigmarun	-0.002246	0.011523	-0.195	**sigmarun**	-0.019825	0.005042	-3.932
QD1				**QD1**			
L1	0.403418	0.007308	55.205	**L1**	0.453421	0.009428	48.094
L2	0.227509	0.007808	29.137	**L2**	0.329532	0.010145	32.481
L3	0.003243	0.007903	0.410	**L3**	0.004874	0.010512	0.464
L4	0.122669	0.007900	15.528	**L4**	0.089605	0.010444	8.580
L5	-0.007564	0.007804	-0.969	**L5**	-0.028366	0.010059	-2.820
L6	0.078395	0.007304	10.733	**L6**	0.060085	0.009312	6.453
_cons	0.156701	0.022683	6.908	**_cons**	0.121629	0.015087	8.062
QD2				**QD2**			
buyinit	-0.033699	0.037354	-0.902	**buyinit**	0.028914	0.027405	1.055
qatask	0.203503	0.053289	3.819	**qatask**	-0.033769	0.040462	-0.835
qatbid	0.120217	0.055256	2.176	**qatbid**	-0.000222	0.043064	-0.005
qatask2	-0.008574	0.013317	-0.644	**qatask2**	0.018177	0.006203	2.930
qatbid2	-0.012679	0.013121	-0.966	**qatbid2**	0.011012	0.006009	1.833
askshock	-0.172137	0.051963	-3.313	**askshock**	0.033677	0.039550	0.851
bidshock	-0.108146	0.053547	-2.020	**bidshock**	-0.026945	0.042407	-0.635
sigmarun	0.005941	0.013255	0.448	**sigmarun**	-0.008496	0.006295	-1.350
QD2				**QD2**			
L1	0.302453	0.007292	41.480	**L1**	0.379907	0.009347	40.645
L2	0.251922	0.007522	33.490	**L2**	0.367247	0.009867	37.220
L3	0.023921	0.007707	3.104	**L3**	-0.053936	0.010369	-5.202
L4	0.075533	0.007709	9.798	**L4**	0.093562	0.010368	9.024
L5	0.025385	0.007526	3.373	**L5**	-0.024446	0.009862	-2.479
L6	0.063882	0.007282	8.772	**L6**	0.069263	0.009355	7.404
_cons	0.093780	0.026022	3.604	**_cons**	-0.031040	0.018780	-1.653

QD3				**QD3**			
buyinit	-0.104610	0.037547	-2.786	**buyinit**	-0.005949	0.021378	-0.278
qatask	0.122132	0.053320	2.291	**qatask**	0.097144	0.031665	3.068
qatbid	-0.050235	0.055267	-0.909	**qatbid**	0.017907	0.033584	0.533
qatask2	-0.029090	0.013386	-2.173	**qatask2**	-0.008086	0.004831	-1.674
qatbid2	-0.028436	0.013189	-2.156	**qatbid2**	-0.006024	0.004680	-1.287
askshock	-0.056931	0.052027	-1.094	**askshock**	-0.096239	0.030951	-3.109
bidshock	0.066810	0.053578	1.247	**bidshock**	-0.061896	0.033088	-1.871
sigmarun	0.027756	0.013324	2.083	**sigmarun**	0.008436	0.004902	1.721
QD3				**QD3**			
L1	0.274956	0.007295	37.690	**L1**	0.374147	0.010125	36.951
L2	0.260593	0.007532	34.598	**L2**	0.396546	0.010763	36.844
L3	0.020331	0.007722	2.633	**L3**	-0.018751	0.011448	-1.638
L4	0.097541	0.007722	12.631	**L4**	0.086125	0.011447	7.524
L5	0.019302	0.007531	2.563	**L5**	0.035536	0.010761	3.302
L6	0.042118	0.007297	5.772	**L6**	0.040185	0.010122	3.970
_cons	0.065205	0.026080	2.500	**_cons**	0.033484	0.014691	2.279
QD4				**QD4**			
buyinit	0.058057	0.037854	1.534	**buyinit**	0.030173	0.028651	1.053
qatask	0.015342	0.053683	0.286	**qatask**	0.013729	0.042269	0.325
qatbid	0.160089	0.055722	2.873	**qatbid**	0.118278	0.044974	2.630
qatask2	0.026749	0.013509	1.980	**qatask2**	0.003452	0.006489	0.532
qatbid2	0.024023	0.013309	1.805	**qatbid2**	0.004934	0.006288	0.785
askshock	-0.058070	0.052369	-1.109	**askshock**	0.051202	0.041319	1.239
bidshock	-0.181664	0.054021	-3.363	**bidshock**	-0.126664	0.044303	-2.859
sigmarun	-0.024822	0.013446	-1.846	**sigmarun**	-0.007598	0.006587	-1.154
QD4				**QD4**			
L1	0.285354	0.007128	40.031	**L1**	0.420099	0.008993	46.715
L2	0.293731	0.007351	39.957	**L2**	0.342515	0.009620	35.604
L3	-0.012165	0.007606	-1.599	**L3**	-0.068779	0.010036	-6.853
L4	0.075536	0.007598	9.942	**L4**	0.132643	0.010012	13.249
L5	0.043101	0.007357	5.859	**L5**	-0.061367	0.009606	-6.388
L6	0.033071	0.007127	4.640	**L6**	0.048927	0.008994	5.440
_cons	0.013316	0.026267	0.507	**_cons**	0.002807	0.019638	0.143
QD5				**QD5**			
buyinit	0.027763	0.036772	0.755	**buyinit**	-0.008610	0.023768	-0.362
qatask	-0.020762	0.052149	-0.398	**qatask**	0.060990	0.035280	1.729
qatbid	-0.013029	0.054096	-0.241	**qatbid**	0.001851	0.037412	0.049
qatask2	0.020256	0.013121	1.544	**qatask2**	0.013595	0.005376	2.529
qatbid2	0.019531	0.012927	1.511	**qatbid2**	0.010512	0.005207	2.019
askshock	-0.002056	0.050884	-0.040	**askshock**	-0.059602	0.034500	-1.728
bidshock	-0.008429	0.052450	-0.161	**bidshock**	-0.033401	0.036858	-0.906
sigmarun	-0.021628	0.013060	-1.656	**sigmarun**	-0.009637	0.005456	-1.766
QD5				**QD5**			
L1	0.289997	0.007356	39.425	**L1**	0.412429	0.009434	43.716
L2	0.277653	0.007618	36.447	**L2**	0.342644	0.010159	33.730
L3	-0.008351	0.007830	-1.067	**L3**	0.012484	0.010623	1.175
L4	0.104014	0.007830	13.283	**L4**	0.098336	0.010635	9.246
L5	0.033169	0.007619	4.353	**L5**	-0.042809	0.010159	-4.214
L6	0.048016	0.007356	6.528	**L6**	0.084129	0.009429	8.922
_cons	-0.017872	0.025518	-0.700	**_cons**	0.014172	0.016348	0.867

Q1				**Q1**			
buyinit	0.049202	0.028654	1.717	**buyinit**	0.030597	0.021617	1.415
qatask	0.044240	0.041064	1.077	**qatask**	0.157221	0.031882	4.931
qatbid	0.023447	0.042229	0.555	**qatbid**	0.058869	0.033745	1.745
qatask2	-0.020227	0.010175	-1.988	**qatask2**	-0.010215	0.004850	-2.106
qatbid2	-0.017065	0.010026	-1.702	**qatbid2**	0.002578	0.004698	0.549
askshock	-0.025652	0.040027	-0.641	**askshock**	-0.133044	0.031193	-4.265
bidshock	-0.067757	0.040908	-1.656	**bidshock**	-0.169218	0.033232	-5.092
sigmarun	0.022087	0.010128	2.181	**sigmarun**	0.004307	0.004923	0.875
Q1				**Q1**			
L1	0.392677	0.007240	54.237	**L1**	0.454439	0.009988	45.498
L2	0.348111	0.007722	45.082	**L2**	0.375861	0.010917	34.430
L3	-0.019296	0.008110	-2.379	**L3**	-0.029894	0.011471	-2.606
L4	0.082408	0.008101	10.172	**L4**	0.088812	0.011465	7.746
L5	-0.041280	0.007722	-5.346	**L5**	-0.041605	0.010911	-3.813
L6	0.132355	0.007231	18.304	**L6**	0.036683	0.009940	3.691
_cons	0.000002	0.020071	0.000	**_cons**	0.042395	0.014864	2.852
Q2				**Q2**			
buyinit	0.026340	0.031453	0.837	**buyinit**	0.003481	0.024548	0.142
qatask	0.110827	0.044764	2.476	**qatask**	0.044637	0.036145	1.235
qatbid	0.107808	0.046401	2.323	**qatbid**	0.021253	0.038543	0.551
qatask2	-0.054930	0.011216	-4.898	**qatask2**	0.004765	0.005556	0.858
qatbid2	-0.050310	0.011050	-4.553	**qatbid2**	0.000234	0.005382	0.044
askshock	-0.063326	0.043674	-1.450	**askshock**	-0.084838	0.035343	-2.400
bidshock	-0.063924	0.044982	-1.421	**bidshock**	-0.016099	0.037961	-0.424
sigmarun	0.054435	0.011164	4.876	**sigmarun**	-0.000856	0.005638	-0.152
Q2				**Q2**			
L1	0.361827	0.007245	49.942	**L1**	0.380684	0.009462	40.231
L2	0.360836	0.007648	47.183	**L2**	0.388470	0.010019	38.772
L3	-0.057785	0.008056	-7.173	**L3**	-0.035677	0.010619	-3.360
L4	0.105287	0.008051	13.077	**L4**	0.113364	0.010622	10.673
L5	0.006917	0.007649	0.904	**L5**	-0.019450	0.010020	-1.941
L6	0.066741	0.007244	9.214	**L6**	0.051906	0.009459	5.488
_cons	0.037426	0.021884	1.710	**_cons**	0.013741	0.016806	0.818
Q3				**Q3**			
buyinit	0.002372	0.033970	0.070	**buyinit**	0.042895	0.019279	2.225
qatask	0.034134	0.048288	0.707	**qatask**	0.023548	0.028525	0.826
qatbid	0.023639	0.050034	0.472	**qatbid**	0.158414	0.030473	5.198
qatask2	0.002632	0.012123	0.217	**qatask2**	0.006952	0.004360	1.595
qatbid2	0.002017	0.011944	0.169	**qatbid2**	0.002215	0.004223	0.525
askshock	-0.046386	0.047120	-0.984	**askshock**	-0.075590	0.027892	-2.710
bidshock	-0.011215	0.048506	-0.231	**bidshock**	-0.107118	0.030002	-3.570
sigmarun	-0.004929	0.012066	-0.408	**sigmarun**	-0.005468	0.004424	-1.236
Q3				**Q3**			
L1	0.225544	0.007361	30.639	**L1**	0.404846	0.009991	40.519
L2	0.376275	0.007519	50.043	**L2**	0.437121	0.010732	40.732
L3	-0.011899	0.007976	-1.492	**L3**	-0.061244	0.011569	-5.294
L4	0.089070	0.007974	11.170	**L4**	0.109461	0.011557	9.472
L5	0.050126	0.007521	6.665	**L5**	-0.030935	0.010699	-2.892
L6	0.086581	0.007363	11.759	**L6**	0.070038	0.009986	7.014
_cons	0.015220	0.023614	0.645	**_cons**	0.013167	0.013220	0.996

Q4				**Q4**			
buyinit	0.022373	0.031652	0.707	**buyinit**	0.018836	0.026137	0.721
qatask	0.001600	0.044999	0.036	**qatask**	0.035846	0.038466	0.932
qatbid	0.064847	0.046705	1.388	**qatbid**	0.177491	0.041040	4.325
qatask2	0.000079	0.011294	0.007	**qatask2**	0.008916	0.005914	1.508
qatbid2	-0.001535	0.011128	-0.138	**qatbid2**	-0.000433	0.005730	-0.075
askshock	-0.042245	0.043900	-0.962	**askshock**	-0.076680	0.037601	-2.039
bidshock	-0.069870	0.045260	-1.544	**bidshock**	-0.127828	0.040421	-3.162
sigmarun	0.004973	0.011241	0.442	**sigmarun**	-0.006657	0.006002	-1.109
Q4				**Q4**			
L1	0.334513	0.007152	46.774	**L1**	0.378950	0.009589	39.518
L2	0.350351	0.007501	46.706	**L2**	0.367157	0.010177	36.076
L3	0.023886	0.007839	3.047	**L3**	-0.032753	0.010719	-3.056
L4	0.062452	0.007842	7.964	**L4**	0.108789	0.010714	10.154
L5	-0.001572	0.007505	-0.209	**L5**	-0.047216	0.010160	-4.647
L6	0.097653	0.007155	13.648	**L6**	0.062224	0.009582	6.494
_cons	0.008365	0.021999	0.380	**_cons**	0.031463	0.017889	1.759
Q5				**Q5**			
buyinit	0.083069	0.033137	2.507	**buyinit**	-0.005874	0.021044	-0.279
qatask	0.036842	0.047071	0.783	**qatask**	0.081009	0.031112	2.604
qatbid	0.220401	0.049005	4.498	**qatbid**	0.093371	0.033243	2.809
qatask2	0.001169	0.011816	0.099	**qatask2**	-0.015316	0.004761	-3.217
qatbid2	-0.007207	0.011642	-0.619	**qatbid2**	-0.013858	0.004612	-3.005
askshock	-0.055729	0.045917	-1.214	**askshock**	-0.081925	0.030381	-2.697
bidshock	-0.162412	0.047515	-3.418	**bidshock**	-0.056269	0.032740	-1.719
sigmarun	0.000542	0.011761	0.046	**sigmarun**	0.016659	0.004830	3.449
Q5				**Q5**			
L1	0.350078	0.007354	47.602	**L1**	0.422392	0.010211	41.367
L2	0.321644	0.007766	41.417	**L2**	0.384229	0.011066	34.721
L3	-0.014371	0.008079	-1.779	**L3**	-0.047619	0.011678	-4.078
L4	0.071292	0.008082	8.821	**L4**	0.106531	0.011680	9.121
L5	-0.009737	0.007759	-1.255	**L5**	-0.001246	0.011052	-0.113
L6	0.086292	0.007349	11.742	**L6**	0.032746	0.010207	3.208
_cons	0.013587	0.023017	0.590	**_cons**	0.031119	0.014439	2.155

ANZ				WPL		
Equation	**Obs**	**R-sq**	**Chi2**	**Equation**	**Obs**	**Parms**
dbestbid	28626	0.446	29215	**dbestbid**	30254	0.274
dbestask	28626	0.401	25914	**dbestask**	30254	0.191
spread	28626	0.017	41394	**spread**	30254	0.143
QD1	28626	0.236	10573	**QD1**	30254	0.190
QD2	28626	0.177	8419	**QD2**	30254	0.126
QD3	28626	0.243	11657	**QD3**	30254	0.151
QD4	28626	0.187	7917	**QD4**	30254	0.159
QD5	28626	0.048	1586	**QD5**	30254	0.138
Q1	28626	0.409	21260	**Q1**	30254	0.204
Q2	28626	0.331	16869	**Q2**	30254	0.171
Q3	28626	0.393	20121	**Q3**	30254	0.177
Q4	28626	0.331	16301	**Q4**	30254	0.207
Q5	28626	0.361	19144	**Q5**	30254	0.189
ind. Var	**Coef.**	**Std.**	**Err.**	**ind. Var**	**Coef.**	**Std.**
dbestbid				**dbestbid**		
buyinit	0.006122	0.000403	15.177	**buyinit**	0.002358	0.001550
qatask	0.003182	0.000573	5.551	**qatask**	0.025823	0.002186
qatbid	-0.003632	0.000543	-6.686	**qatbid**	-0.005328	0.002261
qatask2	-0.000066	0.000107	-0.613	**qatask2**	0.000032	0.000408
qatbid2	0.000461	0.000110	4.173	**qatbid2**	0.000870	0.000397
askshock	0.002236	0.000561	3.985	**askshock**	-0.014536	0.002155
bidshock	-0.002360	0.000538	-4.389	**bidshock**	-0.006517	0.002200
sigmarun	-0.000197	0.000110	-1.794	**sigmarun**	-0.000398	0.000409
dbestbid				**dbestbid**		
L1	-0.297148	0.004079	-72.847	**L1**	-0.282713	0.004129
L2	-0.055950	0.004278	-13.077	**L2**	-0.010760	0.004286
L3	-0.072293	0.004238	-17.060	**L3**	-0.055788	0.004247
L4	-0.010917	0.004254	-2.566	**L4**	0.008580	0.004256
L5	-0.032828	0.004163	-7.886	**L5**	-0.026001	0.004174
L6	0.003601	0.003128	1.151	**L6**	0.008784	0.003099
_cons	-0.002957	0.000289	-10.221	**_cons**	0.003791	0.001085
dbestask				**dbestask**		
buyinit	0.004834	0.000384	12.582	**buyinit**	0.001103	0.001515
qatask	0.003296	0.000551	5.979	**qatask**	0.013931	0.002146
qatbid	-0.003289	0.000523	-6.293	**qatbid**	-0.011032	0.002217
qatask2	-0.000067	0.000103	-0.653	**qatask2**	0.000151	0.000399
qatbid2	0.000413	0.000106	3.894	**qatbid2**	0.000898	0.000388
askshock	0.002293	0.000540	4.249	**askshock**	-0.002646	0.002116
bidshock	-0.001953	0.000517	-3.776	**bidshock**	0.000897	0.002158
sigmarun	-0.000193	0.000106	-1.830	**sigmarun**	-0.000497	0.000400
dbestask				**dbestask**		
L1	-0.292097	0.004111	-71.055	**L1**	-0.277552	0.004165
L2	-0.054352	0.004304	-12.629	**L2**	-0.014178	0.004293
L3	-0.070104	0.004260	-16.455	**L3**	-0.054731	0.004254
L4	-0.010239	0.004279	-2.393	**L4**	0.006618	0.004265
L5	-0.032744	0.004188	-7.818	**L5**	-0.022113	0.004182
L6	0.003364	0.003188	1.055	**L6**	0.010063	0.003133
_cons	-0.002376	0.000277	-8.579	**_cons**	-0.000140	0.001069

spread				**spread**		
buyinit	-0.001301	0.000188	-6.923	**buyinit**	-0.001332	0.000685
qatask	0.000049	0.000278	0.176	**qatask**	-0.007663	0.000987
qatbid	0.000207	0.000264	0.783	**qatbid**	-0.001578	0.001012
qatask2	-0.000002	0.000052	-0.047	**qatask2**	0.000078	0.000183
qatbid2	-0.000047	0.000054	-0.868	**qatbid2**	-0.000001	0.000178
askshock	0.000091	0.000272	0.334	**askshock**	0.007723	0.000973
bidshock	0.000525	0.000261	2.010	**bidshock**	0.003258	0.000983
sigmarun	0.000006	0.000054	0.116	**sigmarun**	-0.000061	0.000184
spread				**spread**		
L1	0.564138	0.004278	131.863	**L1**	0.572843	0.004324
L2	0.211298	0.004797	44.047	**L2**	0.257392	0.004790
L3	-0.008436	0.004853	-1.738	**L3**	-0.028437	0.004855
L4	0.055737	0.004848	11.497	**L4**	0.067684	0.004852
L5	-0.011817	0.004796	-2.464	**L5**	-0.019044	0.004747
L6	0.034144	0.004389	7.779	**L6**	0.037418	0.004331
_cons	0.002505	0.000154	16.317	**_cons**	0.000568	0.000494
QD1				**QD1**		
buyinit	-0.293060	0.026737	-10.961	**buyinit**	-0.264064	0.035726
qatask	0.002117	0.039891	0.053	**qatask**	0.007727	0.050729
qatbid	0.344397	0.038310	8.990	**qatbid**	0.289494	0.052760
qatask2	0.018677	0.007399	2.524	**qatask2**	0.010534	0.009514
qatbid2	0.020510	0.007638	2.685	**qatbid2**	0.012456	0.009246
askshock	-0.036778	0.038958	-0.944	**askshock**	-0.022782	0.049972
bidshock	-0.441444	0.037757	-11.692	**bidshock**	-0.346921	0.051208
sigmarun	-0.016939	0.007597	-2.230	**sigmarun**	-0.011143	0.009525
QD1				**QD1**		
L1	0.325600	0.005757	56.557	**L1**	0.343932	0.005650
L2	0.203915	0.005980	34.099	**L2**	0.128431	0.005944
L3	-0.028567	0.006047	-4.724	**L3**	-0.016891	0.005944
L4	0.083497	0.006051	13.800	**L4**	0.070513	0.005948
L5	-0.020683	0.005977	-3.461	**L5**	-0.002332	0.005922
L6	0.065754	0.005767	11.402	**L6**	0.048382	0.005652
_cons	0.242646	0.019850	12.224	**_cons**	0.212654	0.025055
QD2				**QD2**		
buyinit	-0.047655	0.027458	-1.736	**buyinit**	-0.051081	0.036882
qatask	0.118141	0.040871	2.891	**qatask**	-0.044852	0.052490
qatbid	0.084306	0.038931	2.166	**qatbid**	-0.012555	0.054332
qatask2	0.017590	0.007672	2.293	**qatask2**	0.011719	0.009881
qatbid2	0.016267	0.007919	2.054	**qatbid2**	0.010064	0.009602
askshock	-0.127336	0.039966	-3.186	**askshock**	0.035440	0.051731
bidshock	-0.133369	0.038502	-3.464	**bidshock**	-0.006251	0.052768
sigmarun	-0.017990	0.007877	-2.284	**sigmarun**	-0.011675	0.009893
QD2				**QD2**		
L1	0.277870	0.005563	49.948	**L1**	0.313129	0.005627
L2	0.222464	0.005717	38.916	**L2**	0.109702	0.005848
L3	0.006462	0.005827	1.109	**L3**	-0.011272	0.005871
L4	0.067260	0.005821	11.554	**L4**	0.051615	0.005869
L5	0.005838	0.005724	1.020	**L5**	0.041636	0.005851
L6	0.064348	0.005565	11.564	**L6**	0.031466	0.005626
_cons	0.076403	0.020367	3.751	**_cons**	0.014692	0.025889

QD3				**QD3**		
buyinit	-0.016894	0.026336	-0.641	**buyinit**	-0.024508	0.036341
qatask	0.151285	0.039220	3.857	**qatask**	0.011062	0.051705
qatbid	0.081878	0.037283	2.196	**qatbid**	0.017032	0.053499
qatask2	0.008066	0.007361	1.096	**qatask2**	0.008352	0.009737
qatbid2	0.009061	0.007599	1.192	**qatbid2**	0.009202	0.009463
askshock	-0.124546	0.038354	-3.247	**askshock**	-0.021540	0.050966
bidshock	-0.094573	0.036882	-2.564	**bidshock**	-0.062543	0.051973
sigmarun	-0.010031	0.007557	-1.327	**sigmarun**	-0.008880	0.009749
QD3				**QD3**		
L1	0.267948	0.005678	47.187	**L1**	0.302702	0.005625
L2	0.278962	0.005838	47.786	**L2**	0.132811	0.005849
L3	0.042768	0.006026	7.097	**L3**	0.016427	0.005873
L4	0.056315	0.006029	9.341	**L4**	0.078134	0.005872
L5	0.008507	0.005838	1.457	**L5**	0.003170	0.005852
L6	0.057800	0.005682	10.173	**L6**	0.048295	0.005626
_cons	0.055916	0.019544	2.861	**_cons**	0.028103	0.025503
QD4				**QD4**		
buyinit	-0.031401	0.027305	-1.150	**buyinit**	-0.060798	0.036203
qatask	0.155738	0.040582	3.838	**qatask**	-0.023056	0.051496
qatbid	0.041766	0.038617	1.082	**qatbid**	-0.093865	0.053264
qatask2	-0.014114	0.007631	-1.849	**qatask2**	-0.009874	0.009695
qatbid2	-0.016097	0.007878	-2.043	**qatbid2**	-0.013549	0.009422
askshock	-0.136713	0.039699	-3.444	**askshock**	0.022193	0.050760
bidshock	-0.049285	0.038220	-1.289	**bidshock**	0.075401	0.051747
sigmarun	0.017081	0.007835	2.180	**sigmarun**	0.014394	0.009707
QD4				**QD4**		
L1	0.246900	0.005718	43.183	**L1**	0.266689	0.005687
L2	0.237779	0.005862	40.560	**L2**	0.164981	0.005871
L3	0.023482	0.005992	3.919	**L3**	-0.012057	0.005916
L4	0.070091	0.005990	11.701	**L4**	0.093701	0.005916
L5	0.011759	0.005864	2.005	**L5**	0.025291	0.005873
L6	0.048133	0.005716	8.421	**L6**	0.060346	0.005688
_cons	0.060452	0.020233	2.988	**_cons**	0.008876	0.025402
QD5				**QD5**		
buyinit	-0.019657	0.029562	-0.665	**buyinit**	0.007186	0.036633
qatask	0.128983	0.043907	2.938	**qatask**	0.022498	0.052136
qatbid	0.040355	0.041734	0.967	**qatbid**	0.030018	0.053899
qatask2	-0.007064	0.008262	-0.855	**qatask2**	-0.004331	0.009814
qatbid2	-0.007852	0.008529	-0.921	**qatbid2**	-0.003788	0.009538
askshock	-0.113583	0.042943	-2.645	**askshock**	-0.000815	0.051390
bidshock	-0.043211	0.041303	-1.046	**bidshock**	-0.035612	0.052360
sigmarun	0.008603	0.008482	1.014	**sigmarun**	0.002650	0.009826
QD5				**QD5**		
L1	0.112121	0.005867	19.110	**L1**	0.275900	0.005689
L2	0.111507	0.005897	18.909	**L2**	0.155155	0.005885
L3	0.047562	0.005921	8.033	**L3**	0.012619	0.005945
L4	0.055903	0.005922	9.440	**L4**	0.044058	0.005944
L5	0.038370	0.005896	6.508	**L5**	0.017367	0.005886
L6	0.047486	0.005867	8.094	**L6**	0.034885	0.005689
_cons	0.046083	0.021892	2.105	**_cons**	0.009026	0.025715

Q1				**Q1**		
buyinit	0.036316	0.023369	1.554	**buyinit**	0.018595	0.035506
qatask	0.185908	0.034972	5.316	**qatask**	0.230543	0.051006
qatbid	0.052636	0.033176	1.587	**qatbid**	0.099447	0.051992
qatask2	-0.028746	0.006509	-4.417	**qatask2**	-0.038872	0.009431
qatbid2	-0.024909	0.006719	-3.707	**qatbid2**	-0.030555	0.009165
askshock	-0.121589	0.034182	-3.557	**askshock**	-0.160433	0.050201
bidshock	-0.046846	0.032814	-1.428	**bidshock**	-0.030756	0.050516
sigmarun	0.026841	0.006683	4.017	**sigmarun**	0.038518	0.009442
Q1				**Q1**		
L1	0.275530	0.005812	47.404	**L1**	0.251248	0.005650
L2	0.343917	0.006008	57.243	**L2**	0.247195	0.005772
L3	0.030405	0.006313	4.817	**L3**	0.033889	0.005922
L4	0.068138	0.006311	10.796	**L4**	0.058470	0.005912
L5	0.014775	0.006006	2.460	**L5**	-0.008673	0.005773
L6	0.061940	0.005800	10.679	**L6**	0.055029	0.005618
_cons	0.030918	0.017442	1.773	**_cons**	0.046493	0.025150
Q2				**Q2**		
buyinit	0.000677	0.024782	0.027	**buyinit**	-0.025904	0.035990
qatask	0.122276	0.036839	3.319	**qatask**	0.121492	0.051269
qatbid	0.098138	0.035066	2.799	**qatbid**	0.000188	0.052819
qatask2	-0.016154	0.006927	-2.332	**qatask2**	-0.010771	0.009617
qatbid2	-0.012418	0.007150	-1.737	**qatbid2**	-0.005885	0.009347
askshock	-0.117573	0.036038	-3.262	**askshock**	-0.107969	0.050534
bidshock	-0.109032	0.034689	-3.143	**bidshock**	-0.025699	0.051314
sigmarun	0.015757	0.007112	2.216	**sigmarun**	0.008263	0.009629
Q2				**Q2**		
L1	0.270469	0.005579	48.482	**L1**	0.273103	0.005594
L2	0.302672	0.005739	52.737	**L2**	0.196892	0.005760
L3	0.024926	0.005955	4.186	**L3**	0.013090	0.005839
L4	0.087874	0.005950	14.768	**L4**	0.074743	0.005834
L5	0.013385	0.005742	2.331	**L5**	0.017428	0.005760
L6	0.065391	0.005579	11.721	**L6**	0.064231	0.005585
_cons	0.054293	0.018368	2.956	**_cons**	0.048650	0.025296
Q3				**Q3**		
buyinit	-0.020276	0.023589	-0.860	**buyinit**	0.022069	0.035798
qatask	0.116366	0.035105	3.315	**qatask**	0.034566	0.050916
qatbid	0.068977	0.033432	2.063	**qatbid**	0.001764	0.052620
qatask2	-0.001374	0.006594	-0.208	**qatask2**	-0.011116	0.009581
qatbid2	0.000669	0.006807	0.098	**qatbid2**	-0.007542	0.009311
askshock	-0.104870	0.034330	-3.055	**askshock**	-0.015888	0.050191
bidshock	-0.077579	0.033072	-2.346	**bidshock**	-0.005063	0.051122
sigmarun	-0.000723	0.006770	-0.107	**sigmarun**	0.009152	0.009592
Q3				**Q3**		
L1	0.286324	0.005744	49.846	**L1**	0.299617	0.005619
L2	0.311107	0.005949	52.297	**L2**	0.186668	0.005833
L3	0.004385	0.006168	0.711	**L3**	0.016139	0.005881
L4	0.105820	0.006168	17.157	**L4**	0.107945	0.005880
L5	0.038837	0.005949	6.528	**L5**	-0.016849	0.005834
L6	0.043509	0.005745	7.574	**L6**	0.035585	0.005618
_cons	0.052684	0.017500	3.011	**_cons**	-0.001430	0.025123

Q4				**Q4**		
buyinit	0.005499	0.024773	0.222	**buyinit**	-0.077951	0.035143
qatask	0.076617	0.036812	2.081	**qatask**	-0.008152	0.050021
qatbid	0.094253	0.035046	2.689	**qatbid**	-0.186877	0.051711
qatask2	-0.004867	0.006924	-0.703	**qatask2**	0.005216	0.009415
qatbid2	-0.004728	0.007147	-0.661	**qatbid2**	0.009882	0.009150
askshock	-0.075115	0.036009	-2.086	**askshock**	0.019283	0.049313
bidshock	-0.088275	0.034683	-2.545	**bidshock**	0.157216	0.050241
sigmarun	0.004142	0.007109	0.583	**sigmarun**	-0.009478	0.009426
Q4				**Q4**		
L1	0.319379	0.005649	56.541	**L1**	0.284928	0.005682
L2	0.240933	0.005892	40.892	**L2**	0.207718	0.005883
L3	0.015742	0.006022	2.614	**L3**	0.050345	0.005993
L4	0.081482	0.006020	13.535	**L4**	0.018880	0.005994
L5	0.035537	0.005893	6.031	**L5**	0.032275	0.005880
L6	0.069880	0.005646	12.376	**L6**	0.058785	0.005680
_cons	0.037036	0.018356	2.018	**_cons**	-0.002845	0.024673
Q5				**Q5**		
buyinit	0.034492	0.024207	1.425	**buyinit**	-0.053070	0.035527
qatask	0.004816	0.035963	0.134	**qatask**	0.071203	0.050589
qatbid	0.089347	0.034243	2.609	**qatbid**	-0.079679	0.052262
qatask2	0.001596	0.006765	0.236	**qatask2**	0.012341	0.009516
qatbid2	0.004287	0.006983	0.614	**qatbid2**	0.014438	0.009248
askshock	-0.001394	0.035180	-0.040	**askshock**	-0.062746	0.049867
bidshock	-0.109356	0.033890	-3.227	**bidshock**	0.065349	0.050772
sigmarun	-0.003184	0.006945	-0.458	**sigmarun**	-0.014803	0.009528
Q5				**Q5**		
L1	0.312783	0.005627	55.587	**L1**	0.263806	0.005684
L2	0.247611	0.005859	42.260	**L2**	0.230668	0.005868
L3	0.035825	0.005973	5.998	**L3**	0.004291	0.006010
L4	0.114475	0.005973	19.166	**L4**	0.023543	0.006011
L5	0.013626	0.005860	2.326	**L5**	0.033152	0.005868
L6	0.072760	0.005627	12.930	**L6**	0.060308	0.005685
_cons	0.007138	0.017932	0.398	**_cons**	0.022122	0.024949

6.2 Appendices from Chapter 2

6.2.1 Instructions for Random Arrival Experiments

Instructions

**If you have questions that these instructions do not answer, please call or email us to get answers. You should have been given the appropriate TEL# and E-mail address with your initial instructions.

IMPORTANT TEL#s, EMail addresses, and URLs

If you have any questions or comments for us, please contact us via
eeps@hss.caltech.edu
(626) 395-4876 or (626)395-4063

Important announcements will be posted to the following WEB Page during the experiment.
http://hss.caltech.edu/~eeps/news.html

I. HOW THE MARKET WORKS

In the experiment there will be a public market X and in addition each person will have a private market PX###, where ### is the person's ID number. Each of these has a different function but both are important.

In market X, all participants can trade good X. X is traded in a fictitious currency called francs. At the end of the experiment, francs will be worth real money (the exchange rate, which can differ across participants, will be given to you at the time of the experiment) , but units of X will be worth nothing.

You will also have a private market PX###, where ### is your ID number. At random times, you will receive orders from the experimenter that show up in your private market. Only you see the orders in your private market and you choose whether to take advantage of them. These orders have a price and a time tag indicating when the order expires.

The orders in your private market will be either BUY or SELL orders.

BUY orders in your private market mean the experimenter is willing to buy units from you at the prices and quantities listed on the orders. IMPORTANT: In order to make money on BUY orders in your private market you will buy units from the public market and then sell them for higher prices in your private market by filling the experimenter's BUY orders.

SELL orders in your private market mean the experimenter is willing to sell units to you at the prices and quantities listed on the orders. IMPORTANT: If you have SELL orders in your private market you will also be loaned two units of X at the begining of the experiment. When you sell X in the public market, you should replenish your supply by buying X in your private market. **The units of X you are loaned will have to be paid back at the end of the experiment, so make sure to keeps units of X in your inventory**. IMPORTANT: In order to make money on SELL orders in your private market you will have to buy units from the experimenter in your private market and sell them to other subjects in the public market at higher prices than you paid for them.

If you don't have any orders you can profit from immediately, don't worry. New orders will be periodically sent to your private market as the experiment progresses. Each private order is available only for a fixed amount of time, so watch the time tag on each order and act on profitable orders before they expire.

II. HOW YOU MAKE MONEY

THE BEST (AND EASIEST) THING YOU CAN DO TO MAKE MONEY is simply to stay for the whole experiment. The amount of money you can expect to make on each individual trade is relatively small, but if you stay for the whole experiment you will make many trades and the small amounts you make on each trade will quickly add up to large sums.

You will make most of your money by either buying in the public market and reselling in your private market or by buying in your private market and reselling in the public market. You can buy and resell (speculate) in the public market but remember that the X have no value at all. You hold inventories of X only with a risk and be prepared to sell at a loss if you have an inventory and the prices fall. You should not let profitable orders in your private order book expire while holding inventory of X.

EXAMPLE #1

Suppose the best offer in your PRIVATE BUY ORDER BOOK is 200 and the best offer in the PUBLIC SELL ORDER BOOK is 100. If you purchase a unit at the best offer in the public market and resell at the best offer in the private market, you make a profit.

```
Sale in Private Market 200 francs

(You take the experimenter's

buy order.)
```

```
Purchase in Public Market 100 francs

(You place a buy order.)

__________

Profit (added to cash) 100 francs
```

EXAMPLE #2

Suppose the best offer in the PUBLIC BUY ORDER BOOK is 200 and the best offer in the PRIVATE SELL ORDER BOOK is 100. If you purchase a unit at the best offer price in your private market and resell at the best offer price in the public market, you make a profit.

```
Sale in Public Market 200 francs

(You enter a sell order.)

Purchase in Private Market 100 francs

(You take the experimenter's

sell order.)

__________

Profit (added to cash) 100 francs
```

The profits you make are yours to keep.

WARNING!

YOUR WEB PAGE DOES NOT UPDATE AUTOMATICALLY.

REMEMBER THAT THE INFORMATION DISPLAYED BY YOUR WEB BROWSER MAY NOT BE UP-TO-DATE. So when you see a good offer posted in the book and rush to send in a limit order to take it, there is the possibility that someone may beat you to it and that your limit order will either be unfilled or be filled by the next best available offer.

HINTS FOR MAKING MORE MONEY

- Refresh often.

- Be sure to take advantage of offers in your private market before they expire. Periodically checking your private market will help you know what offers are still available.
- Take advantage of profitable trades in your private market before they expire.
- Watch your inventory. Goods are worth nothing outside the experiment; only francs can be exchanged for cash at the end of the experiment.
- The limit orders in your private market need not be acted upon unless you think it is in your interest to do so. In your private market you can select the order that you wish to fill. Since the orders have different expiration time you may want to consider your actions base on both the expiration and the price of the order.

MARKET ORGANIZATION

The market screens should be self-explanatory. You will be free to send buy or sell orders to the public market. Limit orders received will be placed in the public market BOOK unless you choose otherwise. The limit sell orders are arranged from high to low at the top of the page. The limit buy orders will be arranged from low to high starting at the bottom of the page. In the middle of the page, you will see the best (lowest) sell order that is in the book and the best (highest) buy order that is in the book. These orders are displayed publicly for everyone to see.

CASH LOAN In these markets, initially, you will be loaned some amount of cash. There is a good reason for the loan. Without cash the computer would let you do nothing since you are not allowed to have negative cash. However, you must repay the loan before the en d of the experiment. You need not worry about the technology of repaying the loan; the computer will simply take cash away from you at some pre-determined time. The cash will be taken away from you in such a way as not to affect your overall trading capacity.

PERSONAL STATUS PAGE contains the following items.

(1) **CASH ON HAND** Your cash on hand is the running total of your revenue from all sources minus purchases from all sources. (Market sales purchases) At the end of the market, the cash on hand is your profit.

(2) **UNITS**- This is the number of units you have on hand at the moment. Units themselves are worth nothing to you after the market closes.

(3)**OUTSTANDING ORDERS** This is a listing of all orders that you have posted in the market order book. If you want to CANCEL the orders you can do so from this page. You will want to cancel orders that you have posted when you do not want these orders to be taken by other people in the market.

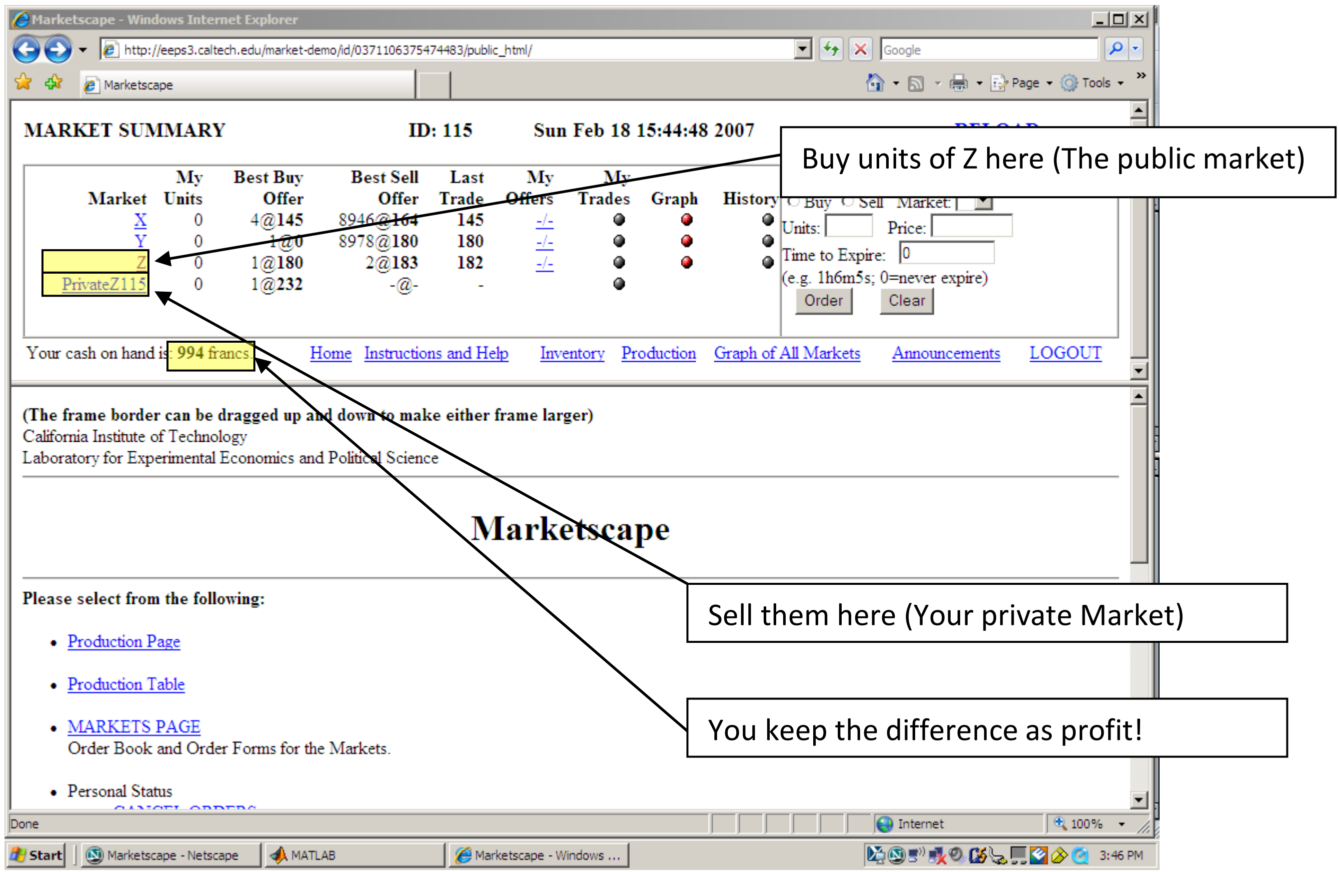
(4) **PERSONAL TRADING RECORDS** Your personal trading record page informs you of trades that you have transacted.

MARKET HISTORY page is a listing of all transactions made by all people. It is a complete account of all trading activity.

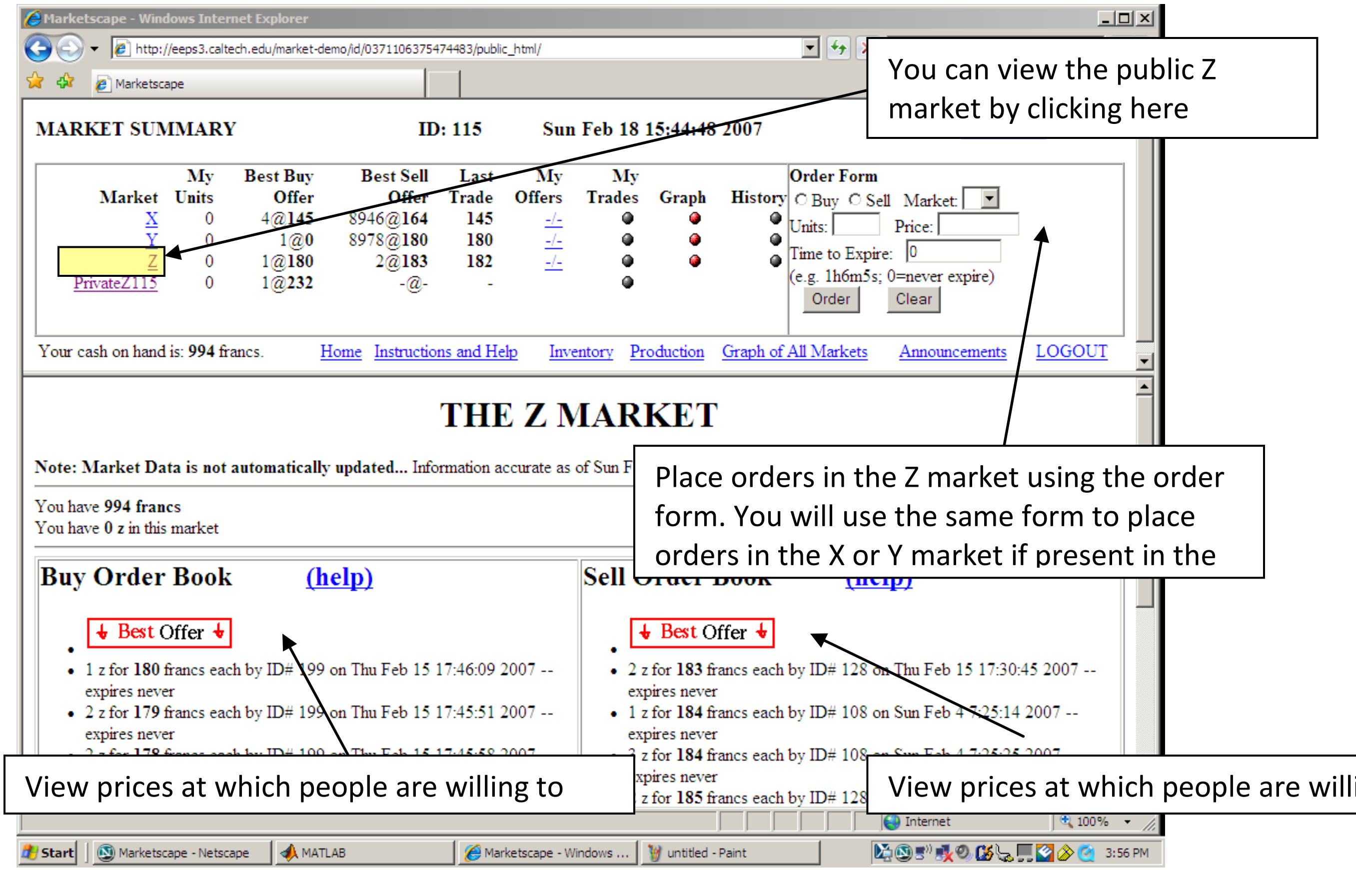
6.3 Appendices from Chapter 4

6.3.1 Help Information Given to All Traders

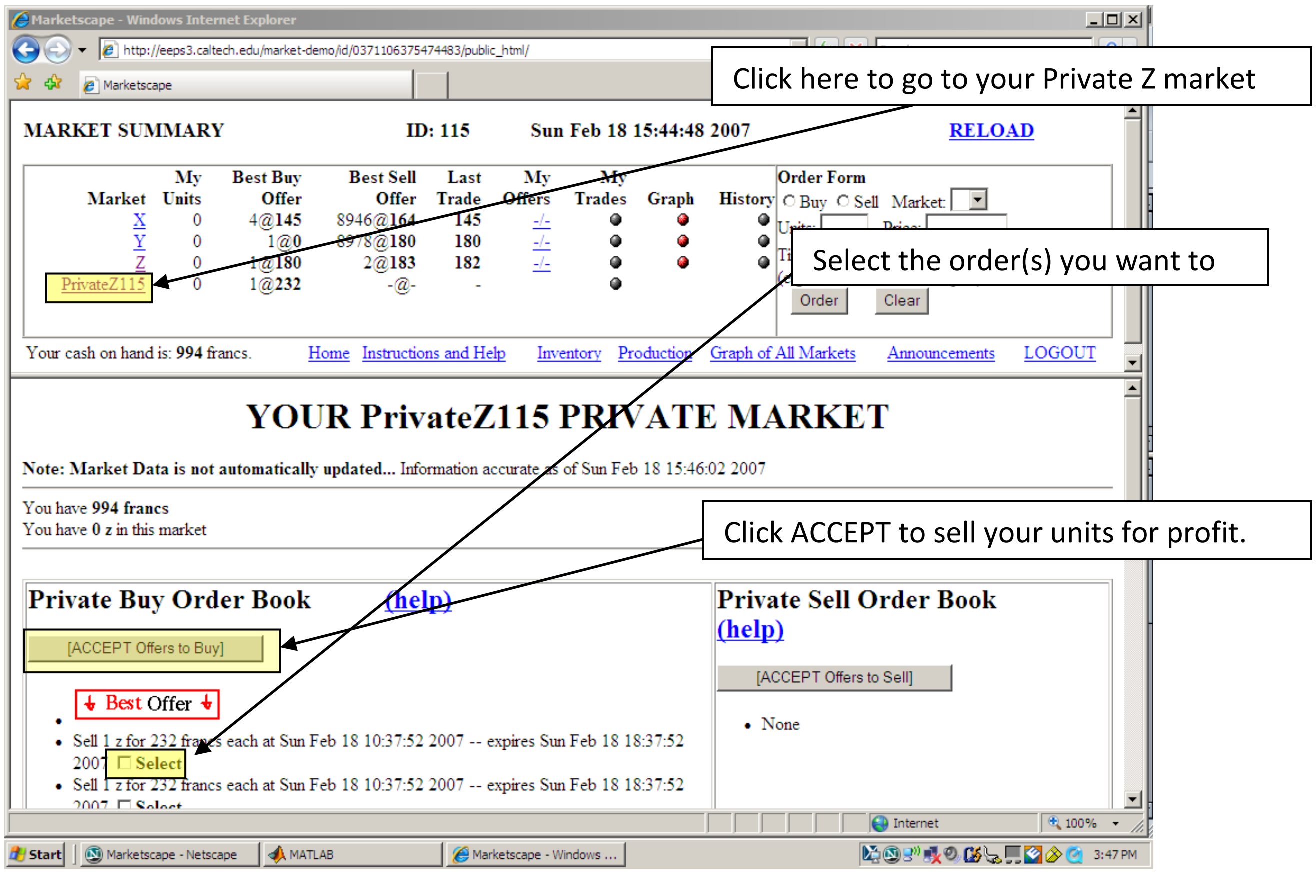
Overview: How to make money as a buyer



The Public Market: Where to buy goods



Your Private Market: Where to sell for profit



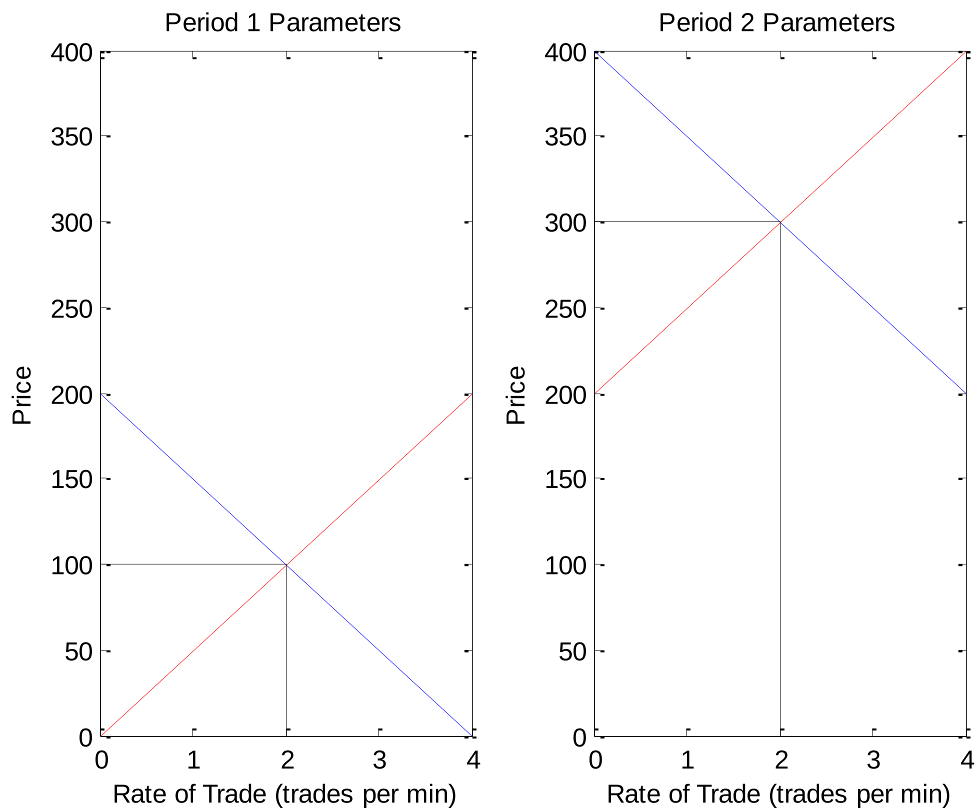
6.3.2 Hand Outs for Insiders and Uninformed Subjects

6.3.2a Introduction Given to All Subjects

About Insiders' Information:

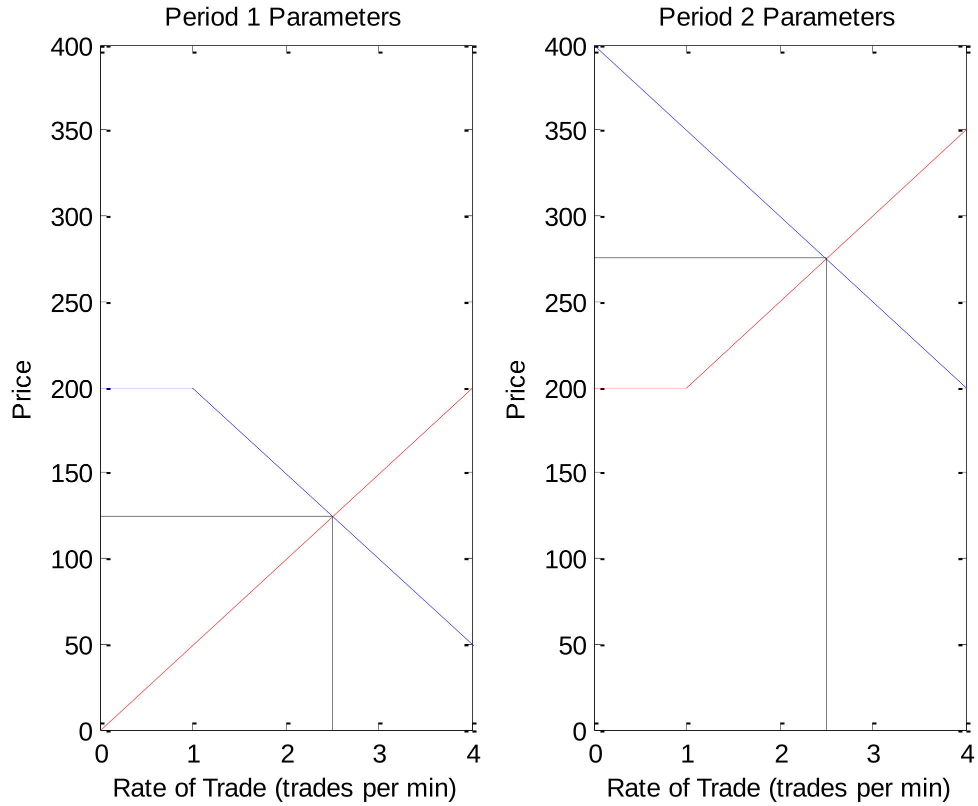
Insiders will know the rate of arrival and distribution of incentives.

Using this information, insiders can compute Supply and Demand curves and hence computer equilibrium prices. For example, if private offers to buy and sell arrived to the market at a rate of 4 offers per minute, and the offers were distributed uniformly between 0 and 200 for the first half of the experiment and uniformly between 200 and 400 for the second half. The supply and demand curves for the first and second half of the experiment would look like this:



The equilibrium prices would be 100 francs and 300 francs respectively, and trade would occur at a rate of 2 trades per minute.

The problem informed traders face is the following:
Since insiders know that prices will be higher in the second half of the experiment, they would like to "speculate." That is, buy cheap units at the beginning of the experiment and sell them for more money during the second half. Unfortunately, this type of speculation shifts the demand curve to the right during the first half of the experiment, and shifts the supply curve to the right during the second half as seen below:



This raises prices in the beginning of the experiment, and lowers prices during the second half of the experiment (cutting into insiders' profits.) If the insiders compete so aggressively that they drive prices up to 200 francs in the first half, and down to 200 francs in the second half, they won't make any profit off their information. In this example, 200 francs is the insiders' "break even point." Every experiment will have a constant break even point, and insiders will know what that price is.

Another problem for informed traders is that uninformed traders may also be watching the trading behavior of informed subjects. These uniformed traders may try to learn about the parameters of the market from the insiders' actions and begin to speculate themselves (cutting into insiders' profits even further.)

Insiders' only goal in this experiment is to make as much money as they can.

Sample insider information:

There will be 4 Buyers and 4 Sellers.

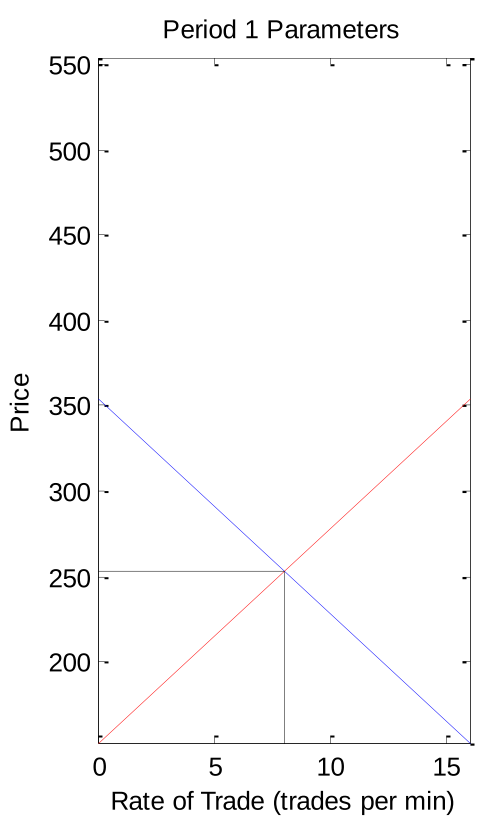
2 of the buyers will be informed, and 2 of the sellers will also be informed. All other buyers and sellers will be uninformed.

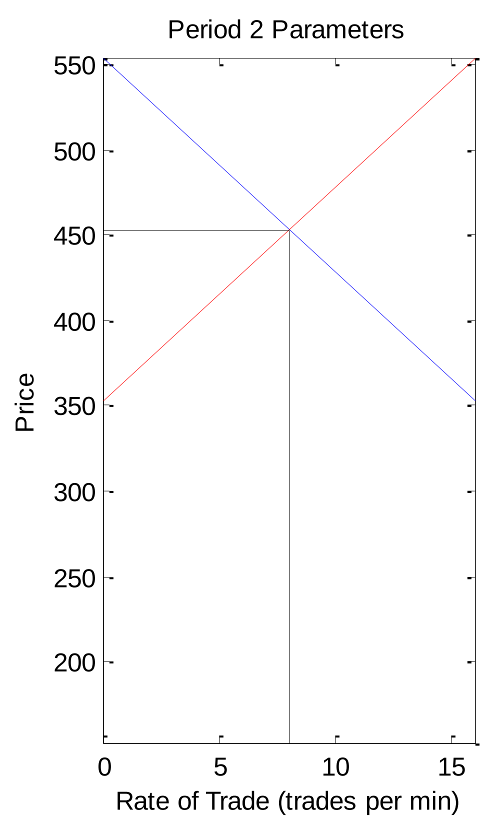
Private offers to buyers will arrive at a rate of 16/min for the whole experiment
Private offers to sellers will arrive at a rate of 16/min for the whole experiment

For the first 30 minutes, prices of private offers will be uniform between 153 and 353
For the second 30 minutes, prices of private offers will be uniform between 353 and 553

The supply and demand equilibrium for the first and second 30 minutes of period 1 are: 250 francs with 8 trades per minute and 450 francs with 8 trades per minute.

The break even point is 350 francs.





Information for Practice Period:

There will be ____ Buyers and ____ Sellers.

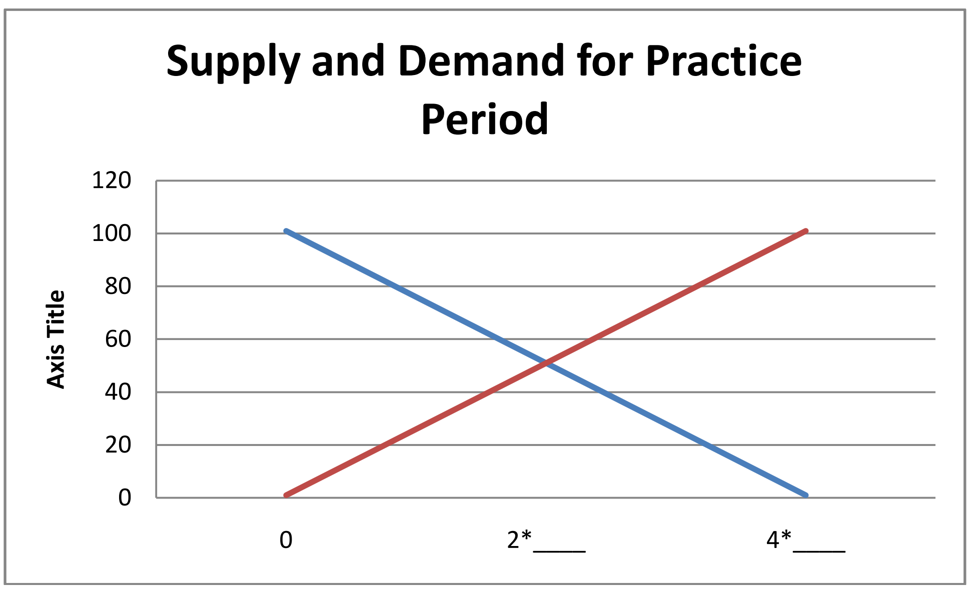
In the practice period, all traders have private markets, and all traders are informed of what the supply and demand equilibrium is. This period is for practice only and earnings earned during this period will not be exchanged for cash.

At the end of the practice period, your loans of cash and inventory will be reset.

Private offers to buyers will arrive at a rate of 4*____ /min= ____ /min for the whole experiment
Private offers to sellers will arrive at a rate of 4*____ /min= ____ /min for the whole experiment

Pprices of private offers will be uniform between 1 and 101

The supply and demand equilibrium for the practice period is: 51 francs with 2*____ /min= ____ /min trades per minute.



6.3.2b Sample of Information Sheet Given to Insiders Only

Information for Period 1:

There will be ____ Buyers and ____ Sellers.

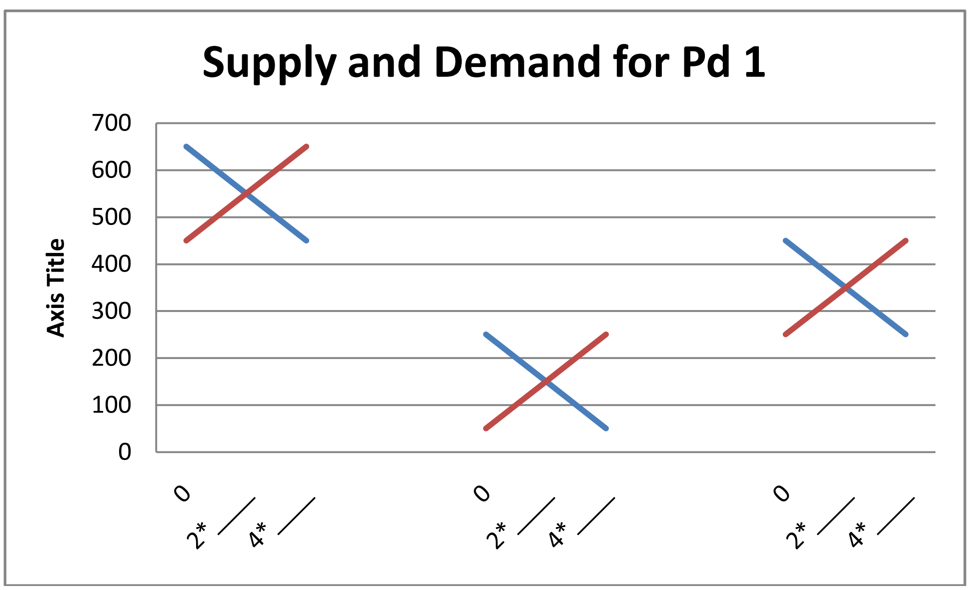
3 of the buyers will be informed, and 3 of the sellers will also be informed. All other buyers and sellers will be uninformed.

Private offers to buyers will arrive at a rate of 4*____ /min= ____ /min for the whole experiment
Private offers to sellers will arrive at a rate of 4*____ /min= ____ /min for the whole experiment

For the first 10 minutes, prices of private offers will be uniform between 450 and 650
For the second 10 minutes, prices of private offers will be uniform between 50 and 250
For the third 10 minutes, prices of private offers will be uniform between 250 and 450

The supply and demand equilibrium are:
First ten minutes: 550 francs with 2*____ /min= ____ /min trades per minute
Second ten minutes: 150 francs with 2*____ /min= ____ /min trades per minute.
Third ten minutes: 350 francs with 2*____ /min= ____ /min trades per minute.

The break even point is 350 francs.



6.3.2c Sample of Information Sheet Given to Non-Insiders

Information for Period 1:

You are not an insider for Period 1. Check your private market for private offers from the experimenter.

PLEASE MAKE SURE YOU MANAGE YOUR INVENTORY PROPERLY.