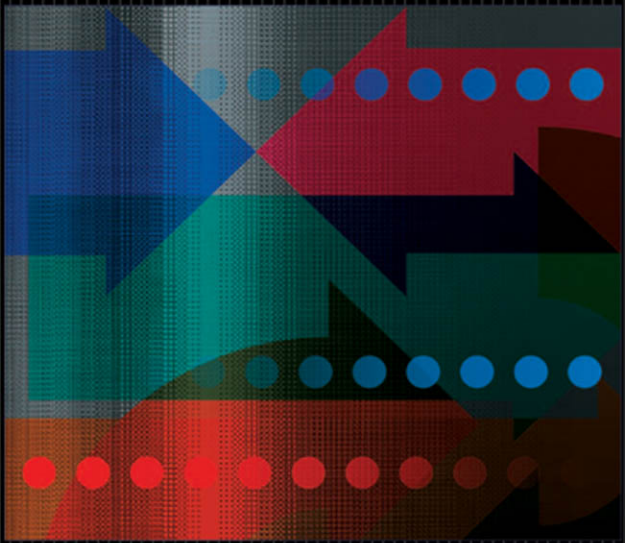
Empirical Market Microstructure

THE INSTITUTIONS, ECONOMICS, AND ECONOMETRICS OF SECURITIES TRADING



JOEL HASBROUCK

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The Institutions, Economics, and Econometrics of Securities Trading

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OXFORD
UNIVERSITY PRESS

2007

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Kuala Lumpur Madrid Melbourne Mexico City Nairobi
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Published by Oxford University Press, Inc.
198 Madison Avenue, New York, New York 10016

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Library of Congress Cataloging-in-Publication Data
Hasbrouck, Joel.
Empirical market microstructure: the institutions, economics, and
econometrics of securities trading/Joel Hasbrouck.
p. cm.
Includes bibliographical references and index.
ISBN-13: 978-0-19-530164-9
ISBN: 0-19-530164-1
1. Securities. 2. Securities—Prices. 3. Investments—Mathematical models.
4. Stock exchanges—Mathematical models. I. Title.
HG4521.H353 2007
332.64—dc22 2006003935

9 8 7 6 5 4 3 2 1

Printed in the United States of America
on acid-free paper

To Lisa, who inspires these pages and much more.

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Preface

This book is a study of the trading mechanisms in financial markets: the institutions, the economic principles underlying the institutions, and statistical models for analyzing the data they generate. The book is aimed at graduate and advanced undergraduate students in financial economics and practitioners who design or use order management systems. Most of the book presupposes only a basic familiarity with economics and statistics.

I began writing this book because I perceived a need for treatment of empirical market microstructure that was unified, authoritative, and comprehensive. The need still exists, and perhaps someday when the field has reached a point of perfection and stasis such a book will be written. In the meantime I simply endeavor to identify and illuminate some themes that appear, for the moment at least, to be defining the field's arc of progress.

Three of these themes are especially prominent. The first is the institution that has come to dominate many of our most important markets—the (electronic) limit order book. Much of the material here can be perceived as an attempt to understand this mechanism. The second theme is asymmetric information, an economic term that refers to the varying quality of the information that traders bring to the market. It often establishes a motive for trade by some individuals, but also frequently leads to costs borne by a larger number. The third theme is linear time-series analysis, a set of statistical tools that have proven to be robust and useful not simply in describing security market data but also in characterizing the underlying economic structure.

Although the institutional, economic, and statistical content of the book can be read separately and selectively, there is a natural ordering to these perspectives. The features of real-world trading mechanisms motivate almost everything else, so an early chapter provides an accessible summary that is largely self-contained. Once this framework has been established, the economic arguments that follow will seem more focused. The statistical time-series models are then brought in to support, refute, or calibrate the economic analyses.

The discussion of time-series analysis here is not as deep as a textbook focused solely on the subject, but it is more substantial than an applied field book would normally attempt. I weave through the book coherent and self-contained explanations of the time-series basics.

This is not done simply to save the reader the trouble of reaching for one of the texts. Coverage, sequencing, and balance in most statistics texts are driven (implicitly at least) by the nature of the data to be modeled. It is a fact that most applications and illustrations in the extant literature of time-series econometrics are drawn from macroeconomics. A theorem is a theorem, of course, irrespective of the sampling frequency. But microstructure data and models are distinctive. It is my hope that seeing time-series analysis organized from a microstructure perspective will help readers apply it to microstructure problems.

Although not presently affiliated, I have over the years served as paid or unpaid consultant or advisor to the New York Stock Exchange, NASDAQ, the Securities and Exchange Commission, and ITG. Except for a brief youthful adventure as a day trader, I lay no claim to trading experience.

One of the earliest comprehensive analyses of U.S. equity markets was the U.S. Securities and Exchange Commission *Special Study of Securities Markets* (1963). Irwin Friend was a consultant to that study and later, among many other things, my dissertation advisor. His supervision was an ongoing lesson in how to approach data with a balance of imagination and skepticism.

All students of market microstructure owe a large debt to the practitioners, who over the years have shared data, patiently described the workings of their markets, and helped us define the important and relevant problems. Jim Cochrane (then of the New York Stock Exchange) opened the door of the exchange to academics, correctly foreseeing that both groups would gain enormously. His efforts have had an enduring positive effect on the research culture of the field.

Other practitioners and regulators who have helped bring us to where we are today include Robert Colby, Michael Edleson, Robert Ferstenberg, Dean Furbush, Frank Hatheway, Rick Ketchum, Ray Killian, Martha Kramer, Tim McCormick, Annette Nazareth, Richard Olsen, Jim Shapiro, James Sinclair, George Sofianos, and David Whitcomb. To these individuals I offer my thanks in lieu of citations.

A partial list of academic researchers who have shaped my thinking and this book would include Yakov Amihud, Bruno Biais, Ian Domowitz, David Easley, Rob Engle, Larry Glosten, Yasushi Hamao, Larry Harris, Tom Ho, Charles Jones, A. S. (Pete) Kyle, Bruce Lehmann, Andrew Lo, Francis Longstaff, Richard Lyons, Ananth Madhavan, Maureen O'Hara, Christine Parlour, Lasse Pedersen, Mark Ready, Gideon Saar, Robert Schwartz, Duane Seppi, Erik Sirri, Matt Spiegel, Chester Spatt, Hans Stoll, Avanidhar (Subra) Subramanyam, S. (Vish) Viswanathan, Jiang Wang, Ingrid Werner, and many others. For encouragement and editorial assistance, I am grateful to Kim Hoag, Catherine Rae, and Terry Vaughn.

I am grateful to the Stern School of New York University for sabbatical support that sustained this work, and to Kenneth G. Langone, who endowed the professorship at Stern that I currently hold. The Business School of Columbia University graciously hosted me as a visitor during the very pleasant year in which this book was completed.

For their suffusion of curiosity, creativity and ebullience, I thank my daughters, Ariane and Siena Hasbrouck.

Contents

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Empirical Market Microstructure

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1 Introduction

1.1 Overview

Market microstructure is the study of the trading mechanisms used for financial securities. There is no "microstructure manifesto," and historical antecedents to the field can probably be found going back to the beginning of written language, but at some point, the field acquired a distinct identity. As good a starting point as any is the coinage of the term *market microstructure* in the paper of the same title by Garman (1976):

> We depart from the usual approaches of the theory of exchange by (1) making the assumption of asynchronous, temporally discrete market activities on the part of market agents and (2) adopting a viewpoint which treats the temporal microstructure, i.e., moment-to-moment aggregate exchange behavior, as an important descriptive aspect of such markets. (p. 257)

Microstructure analyses typically touch on one or more of the following aspects of trade.

1.1.1 Sources of Value and Reasons for Trade

We generally assume that the security value comprises private and common components. Private values are idiosyncratic to the agent and are usually known by the agent when the trading strategy is decided. Common values are the same for everyone in the market and are often known or realized only after trade has occurred. In security markets, the common value component reflects the cash flows from the security, as summarized

in the present value of the flows or the security's resale value. Private value components arise from differences in investment horizon, risk exposure, endowments, tax situations, and so on. Generally, common value effects dominate private value effects. A necessary condition for gains from trade within a set of agents is contingent on some sort of differentiation. In modeling, this is often introduced as heterogeneous private values.

1.1.2 Mechanisms in Economic Settings

Microstructure analyses are usually very specific about the mechanism or protocol used to accomplish trade. One common and important mechanism is the continuous limit order market. The full range, though, includes search, bargaining, auctions, dealer markets, and a variety of derivative markets. These mechanisms may operate in parallel: Many markets are hybrids.

1.1.3 Multiple Characterizations of Prices

The market-clearing price, at least at it arises in usual Walrasian tatonnement, rarely appears in microstructure analyses. At a single instant there may be many prices, depending on direction (buying or selling), the speed with which the trade must be accomplished, the agent's identity or other attribute, and the agent's relationship to the counterparty (as well as, of course, quantity). Some prices (like bids and offers) may be hypothetical and prospective.

1.2 Liquidity

Security markets are sometimes characterized by their *liquidity*. Precise definitions only exist in the contexts of particular models, but the qualities associated with the word are sufficiently widely accepted and understood that the term is useful in practical and academic discourse.

Liquidity impounds the usual economic concept of elasticity. In a liquid market, a small shift in demand or supply does not result in a large price change. Liquidity also refers to the cost of trading, something distinct from the price of the security being bought or sold. Liquid markets have low trading costs. Finally, liquidity has dynamic attributes. In a liquid market, accomplishing a purchase or sale over a short horizon does not cost appreciably more than spreading the trades over a longer interval.

Liquidity is sometimes defined as "depth, breadth, and resiliency." In a deep market if we look a little above the current market price, there is a large incremental quantity available for sale. Below the current price, there is a large incremental quantity that is sought by one or more buyers. A broad market has many participants, none of whom is presumed to

exert significant market power. In a resilient market, the price effects that are associated with the trading process (as opposed to the fundamental valuations) are small and die out quickly.

It is sometimes useful to characterize agents as suppliers or demanders of liquidity. Liquidity supply has traditionally been associated with the financial services industry, that is, the brokers, dealers, and other intermediaries that are sometimes called the sell side of the market. Liquidity demanders in this view are the customers, the individual and institutional investors characterized by trading needs (and sometimes called the buy side).

From a narrower perspective, liquidity supply and demand differentiates agents who are available to trade or offer the option to trade, and those who spontaneously decide to trade. Thus, liquidity suppliers are passive, and demanders are active. In any particular trade, the active side is the party who seals the deal by accepting the terms offered by the passive side. In other words, the passive side "makes" the market and the active side "takes."

With the rise of markets that are widely, directly, and electronically accessible, the role of liquidity demander or supplier (in the sense of the preceding paragraph) is a strategic choice that can be quickly reversed. The alignment of liquidity demand and supply with particular institutions, therefore, is of diminished relevance in many modern markets.

The *liquidity externality* is a network externality. The attributes of liquidity just discussed are generally enhanced, and individual agents can trade at lower cost, when the number of participants increases. This force favors market *consolidation*, the concentration of trading activity in a single mechanism or venue. Differences in market participants (e.g., retail versus institutional investors), however, and innovations by market designers militate in favor of market segmentation (in this context, usually called *fragmentation*).

The number of participants in a security market obviously depends on features of the security, in addition to the trading mechanism. If the aggregate value of the underlying assets is high; if value-relevant information is comprehensive, uniform, and credible; or if the security is a component of an important index, there will be high interest in trading the security. Ultimately, of course, these qualities are determined endogenously with the market mechanism. But it is common, when emphasizing the exogenous aspects of these attributes to describe a *security* as being liquid or illiquid.

The sources and origins of liquidity are generally what this book and the field are about. They defy simplistic generalizations, but I have found one expression to be particularly thought-provoking: "Liquidity is created through a give and take process in which multiple counterparties selectively reveal information in exchange for information ultimately

leading to a trade." The words are taken from the offering materials for the ICor Brokerage (an electronic swaps trading platform). It is a practical sentiment that resonates throughout much of what follows.

1.3 Transparency

Transparency is a market attribute that refers to how much information market participants (and potential participants) possess about the trading process. Electronic markets that communicate in real time the bids and offers of buyers and sellers and the prices of executed trades are considered highly transparent. Dealer markets, on the other hand, often have no publicly visible bids or offers, nor any trade reporting, and are therefore usually considered opaque.

1.4 Econometric Issues

Microstructure data are distinctive. Most microstructure series consist of discrete events randomly arranged in continuous time. Within the time-series taxonomy, they are formally classified as *point processes*. Point process characterizations are becomingly increasingly important, but for many purposes it suffices to treat observations as continuous variables realized at regular discrete times.

Microstructure data are often well ordered. The sequence of observations in the data set closely corresponds to the sequence in which the economic events actually happened. In contrast, most macroeconomic data are time-aggregated. This gives rise to simultaneity and uncertainty about the directions of causal effects. The fine temporal resolution, sometimes described as ultra-high frequency, often supports stronger conclusions about causality (at least in the post hoc ergo propter hoc sense).

Microstructure data samples are typically large in the sense that by most economic standards observations are exceedingly plentiful (10,000 would not be considered unusual). One would not ordinarily question the validity of asymptotic statistical approximations in samples of this size. It is worth emphasizing, though, that the usual asymptotic results apply to correctly specified models, and given the complexity of trading processes, some degree of misspecification is almost inevitable. Furthermore, despite the number of observations, the data samples are often small in terms of calendar span (on the order of days or at best months).

Microstructure data samples are new (we don't have long-term historical data for most markets). The samples may also be characterized as old, though, because market institutions are changing so rapidly that even samples a few years previous may be seriously out of date.

1.5 The Questions

Here is a partial list of significant outstanding questions in market microstructure:

- What are optimal trading strategies for typical trading problems?
- Exactly how is information impounded in prices?
- How do we enhance the information aggregation process?
- How do we avoid market failures?
- What sort of trading arrangements maximize efficiency?
- What is the trade-off between "fairness" and efficiency?
- How is market structure related to the valuation of securities?
- What can market/trading data tell us about the informational environment of the firm?
- What can market/trading data tell us about long-term risk?

Although they might have been worded differently, most of these problems have been outstanding as long as the field has been in existence.

1.6 Readings

This book draws on material from economic theory, econometrics and statistics, and descriptions of existing market institutions. Harris (2003) is a broad treatment of economic theory and trading institutions at the advanced MBA level. O'Hara (1995) is the standard reference for the economic theory of market microstructure. Brunnermeier (2001) surveys information and price formation in securities markets, treating microstructure in a broader economic context. Lyons (2001) discusses the market microstructure of the foreign exchange market, providing a useful alternative to the present treatment, which is based more on equity markets. Survey articles include Hasbrouck (1996a), Madhavan (2000), and Biais, Glosten, and Spatt (2005). Amihud, Mendelson, and Pedersen (2005) survey the rapidly growing field that links microstructure and asset pricing. Shepard (2005) is a useful collection of key readings in stochastic volatility. This research increasingly relies on high-frequency data and therefore more deeply involves microstructure issues.

Some characteristics of security price dynamics are best discussed in context of the larger environment in which the security market operates. Cochrane (2005) is a comprehensive and highly comprehensible synthesis of the economics of asset pricing. Related background readings on financial economics include Ingersoll (1987), Huang and Litzenberger (1998), and Duffie (2001).

The empirical material draws heavily on the econometrics of time-series analysis. Hamilton (1994) is the key reference here, and the present discussion often refers the reader to Hamilton for greater detail. For other

econometric techniques (in particular, duration and limited dependent variable models), Greene (2002) is particularly useful. Alexander (2001), Gourieroux and Jasiak (2001) and Tsay (2002) discuss financial econometrics; Dacorogna et al. (2001) focus on high-frequency data. The econometric coverage in these excellent books partially overlaps with the present text.

It is difficult to cite authoritative sources covering institutional details of the specific markets. Markets that are recently organized or overhauled, particularly those that feature standard mechanisms, are usually well documented. The trading procedures of the Euronext markets are in this respect exemplary (Euronext (2003)). Hybrid markets that have evolved over extended periods of change and adaptation are much less straightforward. The practicalities of current trading on the New York Stock Exchange, for example, would be extremely difficult to deduce from the codified *Constitution and Rules* (New York Stock Exchange (2005)). Comerton-Forde and Rydge (2004) provide useful summaries of trading procedures in many securities markets and countries.

1.7 Supplements to the Book

My Web site (http://www.stern.nyu.edu/~jhasbrou) contains a number of links and programs that may help the reader follow, apply, emend, or extend the material in the book. Most of the mathematical derivations in the book were generated using *Mathematica*. The *Mathematica* notebooks are available on the site. Using *Mathematica* does not by any means guarantee the correctness of a derivation, but it does lessen the likelihood of a simple algebraic mistake. A *Mathematica* notebook documents a calculation in standard form. It facilitates the modification and extension of an argument, visualization, and (when necessary) the transition to numerical implementation. The solutions to most of the exercises are contained in the notebooks. The site has several SAS programs that illustrate the techniques.

2

Trading Mechanisms

This chapter surveys typical trading arrangements and establishes an institutional context for the statistical and economic models to follow. This book focuses on continuous security markets. Whatever their original mechanisms, many and the most visible of these markets presently feature an electronic limit order book. The limit order market, then, is the starting point for the survey. This is probably the most important mechanism, but there are usually at least several alternative paths to accomplishing a trade for any given security. Most security markets are actually hybrids, involving dealers, clearings, one- and two-sided auctions, and bilateral bargaining, all of which are also discussed. The survey emphasizes general features and is not specific to particular securities or a particular country. The appendix to the book contains a supplementary overview of U.S. equity markets.

Whatever the mechanism, the event that we label a trade, execution, or fill (of an order) actually only constitutes a preliminary agreement as to terms. This agreement sets in motion the clearing and settlement procedures that will ultimately result in the transfer of securities and funds. These processes are usually automatic and routine, and the traders seldom need to concern themselves with the details. It is important, though, that they require some sort of preexisting relationship, possibly one that is indirect and via intermediaries, between the parties. Establishing a brokerage account or clearing arrangement is neither costless nor instantaneous and may therefore create a short-run barrier to entry for a potential buyer or seller not previously known to the market.

Trading often involves a broker. A broker may simply provide a conduit to the market but may also act as the customer's agent. This is a more

substantial role and may involve discretion about how to handle a customer's trading needs: when to trade, where to trade, what sort of orders to use, and so on. The customer–broker agency relationship gives rise to the usual problems of monitoring, contracting, and enforcement that pervade many principal–agent relationships. The broker's duty to the customer is sometimes broadly characterized as "best execution," but precise definition of what this means has proven elusive (Macey and O'Hara (1997)).

We now turn to the specific mechanisms.

2.1 Limit Order Markets

Most continuous security markets have at least one electronic limit order book. A limit order is an order that specifies a direction, quantity, and acceptable price, for example, "Buy 200 shares at $25.50 [per share]," or "Sell 300 shares at $30.00." In a limit order market, orders arrive randomly in time. The price limit of a newly arrived order is compared to those of orders already held in the system to ascertain if there is a match. For example, if the buy and sell orders just described were to enter the system (in any order), there would be no match: a price of $25.50 is not acceptable to the seller; a price of $30.00 is not acceptable to the buyer. A subsequent order to buy 100 shares at $32.00 could be matched, however, as there is an overlap in the acceptable prices. If there is a match, the trade occurs at the price set by the first order: An execution will take place (for 100 shares) at $30.

The set of unexecuted limit orders held by the system constitutes the book. Because limit orders can be canceled or modified at any time, the book is dynamic, and in active markets with automated order management it can change extremely rapidly. These markets are usually transparent, with the state of the book being widely visible to most actual and potential market participants. Short of actually trading, there is no better way to get a feel for their mechanics than by viewing the INET book (currently available at www.nasdaqtrader.com) for an actively traded stock (such as Microsoft, ticker symbol MSFT). The extraordinary level of transparency traders currently enjoy is a recent phenomenon. New York Stock Exchange (NYSE) rules historically prohibited revelation of the book. In the 1990s, this was relaxed to permit visibility of the book on the trading floor. Off-floor visibility was not available until January 2002.[1]

A market might have multiple limit order books, each managed by a different broker or other entity. Limit order books might also be used in conjunction with other mechanisms. When all trading for a security occurs through a single book, the market is said to be organized as a consolidated limit order book (CLOB). A CLOB is used for actively traded stocks in most Asian and European markets.