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Three Essays on Market Depth in Futures Markets

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

THREE ESSAYS ON MARKET DEPTH IN FUTURES MARKETS

A dissertation submitted in partial fulfillment of

the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

BUSINESS ADMINISTRATION

by

Alexandre Aidov

2013

To: Dean David R. Klock
College of Business Administration

This dissertation, written by Alexandre Aidov, and entitled Three Essays on Market Depth in Futures Markets, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

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Date of Defense: August 2, 2013

The dissertation of Alexandre Aidov is approved.

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Florida International University, 2013

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DEDICATION

I dedicate this dissertation to my wife and my daughter. Without their unbridled support and love, the completion of this work would not have been possible.

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I would like to thank all my professors at FIU who imparted their knowledge and expertise upon me. I would like to thank my committee members for their support in the writing of this dissertation. I would like to thank Dr. Holder and the CME Group for providing the market depth data I analyze. I would like to acknowledge and thank Dr. Mishra for the encouragement she provided. I would like to thank Dr. Prakash for providing me with the opportunity to obtain this life changing degree. Most importantly, I would like to thank my dissertation chair, Dr. Daigler for his guidance and for putting me on track to succeed not only in academia but in life.

ABSTRACT OF THE DISSERTATION
THREE ESSAYS ON MARKET DEPTH IN FUTURES MARKETS

by

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Liquidity is an important market characteristic for participants in every financial market. One of the three components of liquidity is market depth. Prior literature lacks a comprehensive analysis of depth in U.S. futures markets due to past limitations on the availability of data. However, recent innovations in data collection and dissemination provide new opportunities to investigate the depth dimension of liquidity.

In this dissertation, the Chicago Mercantile Exchange (CME) Group proprietary database on depth is employed to study the dynamics of depth in the U.S. futures markets. This database allows for the analysis of depth along the entire limit order book rather than just at the first level.

The first essay examines the characteristics of depth within the context of the five-deep limit order book. Results show that a large amount of depth is present in the book beyond the best level. Furthermore, the findings show that the characteristics of five-deep depth between day and night trading vary and that depth is unequal across levels within the limit order book. The second essay examines the link between the five-deep market depth and the bid-ask spread. The results suggest an inverse relation between the spread and the depth after adjusting for control factors. The third essay explores

transitory volatility in relation to depth in the limit order book. Evidence supports the relation between an increase in volatility and a subsequent decrease in market depth. Overall, the results of this dissertation are consistent with limit order traders actively managing depth along the limit order book in electronic U.S. futures markets.

TABLE OF CONTENTS

CHAPTER	PAGE
1. INTRODUCTION	1
1.1. Liquidity and Depth.....	1
1.2. Objectives of this Dissertation	2
1.3. Background of the Database.....	4
1.4. Decoding the Database.....	5
1.5. Characteristics of the Database	8
2. CHARACTERISTICS OF FIVE-DEEP DEPTH IN FUTURES MARKETS.....	14
2.1. Introduction	14
2.2. Literature Review	15
2.3. Data	16
2.4. Methodology	18
2.5. Results	20
2.5.1. Duration and Summary	20
2.5.2. Symmetry and Equality	21
2.6. Conclusion.....	23
3. THE RELATION BETWEEN DEPTH AND SPREAD.....	60
3.1. Introduction	60
3.2. Literature Review.....	61
3.3. Data	63
3.4. Methodology	65
3.4.1. Behavior of Depth and Spread	65
3.4.2. Relation between Depth and Spread	67
3.5. Results	68
3.5.1. Summary Statistics.....	68
3.5.2. Intraday Patterns.....	70
3.5.3. Relation Between Depth and Spread.....	70
3.6. Conclusion.....	71
4. THE RELATION BETWEEN DEPTH AND VOLATILITY	115
4.1. Introduction	115
4.2. Literature Review	116
4.3. Data	117
4.4. Methodology	118
4.4.1. Variables	118
4.4.2. Hypotheses.....	120
4.5. Results	122
4.5.1. Summary Statistics.....	122
4.5.2. Depth and Volatility.....	123
4.5.3. Depth and Volatility with Control Factors	124

4.6. Conclusion.....	125
5. CONCLUSION.....	158
REFERENCES	159
VITA.....	162

LIST OF TABLES

TABLE	PAGE
1.1 RLC Data Message Descriptions	10
1.2 Encoded Contracts and Dates	11
1.3 Trade Activity Summary.....	12
1.4 Contract Specifications	13
2.1 Decoded Contracts and Dates	24
2.2 Depth Flag Updates.....	25
2.3 Duration Day and Night.....	28
2.4 Individual Depth Level Summary.....	29
2.5 Aggregate Depth Level Summary	33
2.6 Additional Depth Summary	37
2.7 Comparison of Moments.....	40
2.8 Symmetry of Depth Levels	41
2.9 Equality of Depth Levels	42
2.10 Equality of Depth Level Pairs.....	43
2.11 Depth Comparison between Day and Night	46
3.1 Open Outcry and Non-Open Outcry Trading Hours.....	73
3.2 Summary Five-Minute Day	74
3.3 Summary Fifteen-Minute Day	76
3.4 Summary Five-Minute Night.....	78
3.5 Summary Fifteen-Minute Night.....	80
3.6 T-note Intraday Patterns of Depth and Spread.....	82

3.7 Corn Intraday Patterns of Depth and Spread	84
3.8 Oil Intraday Patterns of Depth and Spread	86
3.9 Euro Intraday Patterns of Depth and Spread.....	88
3.10 Yen Intraday Patterns of Depth and Spread.....	90
3.11 Gold Intraday Patterns of Depth and Spread	92
3.12 T-note Futures Depth Spread Relation	94
3.13 Corn Futures Depth Spread Relation	96
3.14 Oil Futures Depth Spread Relation	98
3.15 Euro Futures Depth Spread Relation	100
3.16 Yen Futures Depth Spread Relation	102
3.17 Gold Futures Depth Spread Relation	104
4.1 Summary Volatility Five-Minute Day	126
4.2 Summary Volatility Fifteen-Minute Day	127
4.3 Summary Volatility Five-Minute Night.....	128
4.4 Summary Volatility Fifteen-Minute Night	129
4.5 Depth Quantity and Transitory Volatility Five-Minute Day	130
4.6 Depth Frequency and Transitory Volatility Five-Minute Day	131
4.7 Depth Quantity and Transitory Volatility Fifteen-Minute Day	132
4.8 Depth Frequency and Transitory Volatility Fifteen-Minute Day	133
4.9 Depth Quantity and Transitory Volatility Five-Minute Night.....	134
4.10 Depth Frequency and Transitory Volatility Five-Minute Night.....	135
4.11 Depth Quantity and Transitory Volatility Fifteen-Minute Night.....	136

4.12 Depth Frequency and Transitory Volatility Fifteen-Minute Night.....	137
4.13 Depth Quantity, Transitory Volatility, and Controls Five-Minute Day.....	138
4.14 Depth Frequency, Transitory Volatility, and Controls Five-Minute Day.....	141
4.15 Depth Quantity, Transitory Volatility, and Controls Fifteen-Minute Day	144
4.16 Depth Frequency, Transitory Volatility, and Controls Fifteen-Minute Day	146
4.17 Depth Quantity, Transitory Volatility, and Controls Five-Minute Night	148
4.18 Depth Frequency, Transitory Volatility, and Controls Five-Minute Night	151
4.19 Depth Quantity, Transitory Volatility, and Controls Fifteen-Minute Night.....	154
4.20 Depth Frequency, Transitory Volatility, and Controls Fifteen-Minute Night.....	156

LIST OF FIGURES

FIGURE	PAGE
2.1 Depth Message Updates.....	47
2.2 Distribution of T-note Futures Best Depth (Top) and Total Depth (Bottom).....	48
2.3 Distribution of Corn Futures Best Depth (Top) and Total Depth (Bottom)	49
2.4 Distribution of Oil Futures Best Depth (Top) and Total Depth (Bottom)	50
2.5 Distribution of Euro Futures Best Depth (Top) and Total Depth (Bottom)	51
2.6 Distribution of Yen Futures Best Depth (Top) and Total Depth (Bottom).....	52
2.7 Distribution of Gold Futures Best Depth (Top) and Total Depth (Bottom)	53
2.8 T-note Futures Depth	54
2.9 Corn Futures Depth.....	54
2.10 Oil Futures Depth.....	55
2.11 Euro Futures Depth	55
2.12 Yen Futures Depth	56
2.13 Gold Futures Depth.....	56
2.14 Limit Order Book for T-note Futures	57
2.15 Limit Order Book for Corn Futures	57
2.16 Limit Order Book for Oil Futures	58
2.17 Limit Order Book for Euro Futures	58
2.18 Limit Order Book for Yen Futures	59
2.19 Limit Order Book for Gold Futures	59
3.1 Distribution of T-note Futures Best Spread (Top) and Total Spread (Bottom).....	106
3.2 Distribution of Corn Futures Best Spread (Top) and Total Spread (Bottom).....	107

3.3 Distribution of Oil Futures Best Spread (Top) and Total Spread (Bottom)	108
3.4 Distribution of Euro Futures Best Spread (Top) and Total Spread (Bottom).....	109
3.5 Distribution of Yen Futures Best Spread (Top) and Total Spread (Bottom).....	110
3.6 Distribution of Gold Futures Best Spread (Top) and Total Spread (Bottom).....	111
3.7 T-note Futures Depth and Spread Behavior.....	112
3.8 Corn Futures Depth and Spread Behavior	112
3.9 Oil Futures Depth and Spread Behavior	113
3.10 Euro Futures Depth and Spread Behavior	113
3.11 Yen Futures Depth and Spread Behavior.....	114
3.12 Gold Futures Depth and Spread Behavior	114

CHAPTER 1: INTRODUCTION

1.1. Liquidity and Depth

Liquidity is an important characteristic for participants in every financial market. Asset managers and investors desire liquidity because assets with liquidity are less expensive to trade. Moreover, liquidity is important to market makers because of the time varying nature of liquidity and its connection to order submission strategies.

A subjective description of liquidity is the ability to execute trades with both immediacy and a minimum price impact. In other words, in a liquid market securities trade quickly and at a fair market value. However, liquidity is not easily measured due to its multidimensionality. Kyle (1985) proposes a solution to this liquidity measurement conundrum by decomposing liquidity into three dimensions, namely resiliency, tightness, and depth. Resiliency refers to the speed of convergence of prices after information shocks; tightness is the cost of making a transaction over a short period of time; depth refers to the absorption of quantity without a large price impact. In particular, Kyle (1985) measures depth as the inverse of the liquidity parameter measuring the amount of order flow needed to drive up the security price by one unit of price. Therefore, a deep market is one where large orders do not shift prices (significantly), i.e. the liquidity parameter is large.

Recent literature interprets the meaning of depth in different ways. In fact, no one consensus exists regarding the definition and calculation of depth. The modern definition of depth is the ability to buy or sell a certain amount of an asset without affecting the quoted price. This ability is often quantified as the depth available to trade at the best bid and ask prices. Since the quantity of depth is not always available (typically due to data

constraints), researchers have proposed proxies for depth, such as open interest. However, recent innovations in data collection and dissemination provide new opportunities to investigate the depth dimension of liquidity. In particular, depth data past the best bid-ask level for futures markets is now available, when it previously did not exist due to the lack of data from floor trading. This new data now allows for the analysis of depth along the entire limit order book, rather than just at the first level. The focus of this dissertation is on the depth dimension of liquidity in futures markets using a five-deep electronic limit order book. This is the first application of the CME Group five-deep dataset to examine depth in futures markets.

1.2. Objectives of this Dissertation

Market depth illustrates how much trading interest exists at a particular price level. Similarly, depth illustrates the degree of order flow for the market at specific relative prices. Therefore, an understanding of market depth dynamics in the limit order book is essential for both market makers and market participants. In fact, prior research in other markets shows that the amount of depth in the limit order book provides important information concerning the trading decisions of market participants. In addition, use of depth information past the best bid and ask also contributes to the price discovery process.¹

Even though the entire limit order book is important for gauging depth dynamics, research on depth typically was restricted to the first level, as well as limited to stocks and international futures markets. In particular, depth data for floor-traded U.S. futures

¹ See Cao, Hansch, and Wang (2009).

markets are unavailable for study because such data is not collected from individual floor trader's books. More recently, depth data from electronic trading has been recorded, but was still unavailable to researchers. Consequently, prior studies examining the "depth" for U.S. futures markets only employ depth proxies such as open interest or internationally using depth at a single level. I have obtained proprietary market depth for U.S. futures contracts containing five-deep depth data that is employed in this dissertation.

In chapter 2, I examine the characteristics of the five levels of depth for high-frequency U.S. electronic futures markets by using the Chicago Mercantile Exchange (CME) Group's proprietary database on depth. The research objectives for this chapter are to analyze the distribution of depth across the five depth levels and to examine the characteristics of depth at each level. These aspects of futures markets are examined for both day and night trading.

In chapter 3, I examine the relation between five-deep market depth and bid-ask spreads, including the associated intraday patterns of the depth and spread. This analysis extends past research that examines the temporal patterns of (only) the first depth level (the depth available at the best bid and ask level) as provided by market participants in their order submission strategies. This analysis helps to resolve the disagreement concerning the intraday pattern of depth occurring in past research.²

In chapter 4, I explore the volatility of futures markets in relation to the depth of the limit order book. The research objectives of this chapter are to examine the impact of

² Brockman and Chung (1999) find inverted U-shape intraday depth patterns for Honk Kong Stock Exchange securities, whereas Frino, Lepone, and Wearin (2008) find increasing intraday depth patterns for Australian interest rate futures.

lagged volatility on depth. Prior research posits that volatility does affect depth, although the conclusions concerning the form of this relation are not consistent. For example, Ahn, Bae, and Chan (2001) find that a rise in transitory volatility is followed by an increase in market depth. Alternatively, Coppejans, Domowitz, and Madhavan (2001) show that a volatility shock reduces depth.

Overall, the goal of this dissertation is to determine the characteristics of five-deep market depth, as well as the relation of market depth to the bid-ask spread and volatility for the relatively recent U.S. electronic futures contracts. The resulting objective is to provide a thorough investigation of depth for futures markets leading to a better understanding of market depth behavior.

1.3. Background of the Database

A key aspect of the uniqueness of this dissertation is the use of the CME Group database on five-deep depth data for futures markets. The data for this dissertation is generously provided by the CME Group. The CME Group formed in 2007 when the Chicago Mercantile Exchange (CME) and the Chicago Board of Trade (CBOT) merged. In 2008 NYMEX Holdings was acquired by the CME Group as well. The CME Group currently consists of four designated contract markets, namely which are the CME, CBOT, NYMEX and COMEX, making it one of the largest futures marketplaces in the world. According to the Futures Industry Association, by 2008 the CME Group ranked first by the volume of futures and options traded/cleared.

The CME Group supports three trading platforms. The first platform is floor trading through the so-called open outcry method. The second platform is over-the-counter trading/clearing through ClearPort. Finally, the third platform is electronic trading

through the Globex trading platform. The data employed in this dissertation is electronically traded via the CME Globex electronic trading platform.

Futures contracts trade on the CME Globex in three different regimes. The first schedule is labeled side-by-side trading and it occurs when contracts trade electronically on the CME Globex for the non-open outcry portion of the day and simultaneously trade electronically on the Globex as well as the trading floor for the open outcry portion of the day. The second schedule is electronic only trading, which occurs when contracts trade solely electronically on the CME Globex. The third schedule is termed after-hours electronic trading, where contracts trade electronically on the CME Globex during the non-open outcry period and are solely floor traded during the open outcry period. The futures contracts considered in this dissertation employ the side-by-side schedule. In this case, the futures trade both electronically as well as via the floor during the open outcry period. During the non-open outcry period, the futures trade solely electronically. All of the data used in this dissertation comes from electronic trading since depth data for floor trading is not available. The electronic trading during the open outcry period is labeled as “day” trading and the electronic trading during the non-open outcry period is labeled as “night” trading. Before the data is used in the empirical analysis, it is first decoded.

1.4. Decoding the Database

The market depth data from the CME Group database is encoded in the “RLC format,” which contains all of the market data messages required to reconstruct the limit order book. The RLC formatted market data messages consist of two book messages and three price messages. The first book message is called the MA message and it details the five best depth levels on both the bid and ask sides of the book. Whenever the depth

information (quantity or price) changes at any level, a new MA messages is created to update the depth in the limit order book. The second book message is the MY message, and it represents information on implied orders.³ The three price messages are the M0 (last best price) messages, the M5 (opening trade of the day) messages, and the M6 (trade) messages. In this dissertation, I employ depths and trades for the outright futures contracts and therefore the messages of importance are the MA, M5, and M6 messages.

Each of the market data messages contains a specific number of characters and the position of the characters represents a certain attribute of the limit order book. The MA message contains a minimum of 154 and a maximum of 512 characters, the M5 message contains 163 characters, and the M6 message contains 208 characters. Table 1 displays the character positions and descriptions for the MA, M6, and M5 messages. The MA messages contain information about the date and time the message is generated (positions 18-31); the granularity of the time stamp is to the nearest centisecond (1/100 of a second). Positions 77-81 represent a change of depth indicator that takes a value of one if a depth level is updated and zero otherwise. For example, if the character positions 77-81 are provided as “10001”, this means that depth (quantity and/or price) changes only for the first and fifth depth levels. On the other hand, if the character positions 77-81 are provided as “00100”, this states that depth only changes for the third level. When a depth flag is equal to “1” in any position between 77 and 81, the bid depth, bid price, ask depth, and ask price are provided. The M5 and M6 messages provide information about the

³ According to the CME Group, an implied order, “...is an order created from individual outright orders available in the marketplace.” MY messages only contain information for the first two depth levels. Outright messages are single contracts trades, and do not include spreads or combination orders.

trade date and time, trade volume, and trade price in positions 18-31, 70-81, and 82-100, respectively.

The decoding process is summarized as follows. For a given calendar date, a text file contains all five types of market data messages. For each calendar date, the MA, M5, and M6 market data messages are extracted and labeled according to the positions described in Table 1.1. The extracted market data messages are then merged sequentially to obtain a depth file (consisting of MA messages) and a separate trade file (consisting of M6 and M5 messages).

The depth and trade files are filtered and cleaned in a variety of ways. First there is an adjustment for holidays. Although the market is often closed on holidays, some futures contracts have partial pre-holiday and post-holiday trading such that the day before or after a holiday contains extended trading halts. In order to address potential complications due to a lack of intraday data, a date is marked for deletion if it lands on a holiday or contains extended trading breaks either preceding or following a holiday. Holidays include Martin Luther King Day, Presidents Day, Good Friday, Memorial Day, the Fourth of July, Labor Day, Columbus Day, Veterans Day, Thanksgiving, Christmas, and New Year's holiday. Additionally, days with irregular depth reporting are excluded from the sample. I define irregular depth reporting in one of two ways. First, if the first depth update occurs more than two hours after the market opens on a given trade date, that trade date is deleted. Second, if the last depth update for a given trade date occurs before the end of the open outcry portion of the day, then that trade date is deleted from the sample. Moreover, market messages are also filtered for appropriate values. For example, the Trading Mode attribute (MA message position 71) takes a value of 0 in the

preopening mode, 1 in the opening mode, and 2 in the continuous trading mode; only messages during the continuous trading mode are retained. Once the data is cleaned, it is used to analyze depth characteristics and depth behavior in the ensuing chapters.

1.5. Characteristics of the Database

The CME Group database I employ contains six different futures contracts from five different categories representing contracts in interest rates, agriculture, energy, foreign exchange, and metals. The specific futures contracts are the 10-Year U.S. Treasury note, corn, light sweet crude oil (WTI), euro/U.S. dollar, yen/U.S. dollar, and gold futures. Table 2 lists the futures contracts and dates included in the database.⁴ The data for each futures contract begins in January 2008 and runs to March, April, or October 2009, depending on the contract.⁵ The ticker symbols listed in Table 1.2 correspond to the contract symbol for electronic trading. The original size of the encoded data sets for the futures contracts range from 58.1 gigabytes for the T-note futures to 1.09 terabytes for oil futures. Thus, the sizes of the data sets are large and require substantial computer resources to decode and process.⁶

The futures contracts employed in this study are all heavily traded and represent the dominant contracts in their respective categories. Table 1.3 describes the overall

⁴ For ease of exposition the contracts will be referred to as: 10-Year U.S. Treasury note futures as “T-note,” corn futures as “corn,” light sweet crude oil (WTI) futures as “oil,” euro/U.S. dollar futures as the “euro,” yen/U.S. dollar futures as “yen,” and gold futures as “gold.”

⁵ The last date of availability is based on a change of format in the database. An increase in transparency occurred when the depth level increased from five depth levels to ten depth levels for all contracts, except the foreign exchanged contracts. After this depth increase, MA depth messages are no longer recorded in the RLC format available in the database used in this study, therefore the reason for different ending dates.

⁶ For example, it takes over eight hours to decode the oil futures contract running on a computer equipped with an i7-2600 Intel CPU, 16 GB of ram, and a 500GB SSD. The amount of computer processing time is computer dependent.

amount of trading activity in each contract.⁷ There is a large variation in the volume of trades per contract, ranging from a low of 22,749,569 for the yen futures contract to a high of 189,852,019 for the T-note futures contract. Table 1.3 shows that over 90% of total traded volume takes place electronically. This domination by electronic trading is significant because the CME Globex database employed in this study only contains depth and trade information for electronic trading. Therefore the data used in this dissertation represents the vast majority of market activity in these contracts.

The six futures contracts employed also contain different types of contract characteristics; these characteristics are summarized in Table 1.4. The futures contracts belong to one of the four designated contract markets of the CME Group, which include the CME, CBOT, NYMEX and COMEX. The contract sizes are different for each contract, primarily since they are based on different types of underlying futures. All of the contracts are quoted in dollars and cents, except for the T-note futures contract which is quoted in points. The tick sizes, or minimum price increments, also vary for each contract. In summary, the sample of contracts employed in this dissertation consists of six futures contracts traded electronically on the CME Globex system. This dissertation examines the characteristics and behavior of five-deep market depth for these contracts.

⁷ The trade activity represented in this table includes all expirations.

Table 1.1 RLC Data Message Descriptions

This table presents the breakdown of the MA (depth), M5 (opening trades), and M6 (trade) messages. Each message is encoded as a string and decoded based on the position of the characters below.

MA Message		M5 Message		M6 Message	
Position	Attribute	Position	Attribute	Position	Attribute
1 – 12	ISIN Code	1 – 12	ISIN Code	1 – 12	ISIN Code
13 – 17	Timestamp	13 – 17	Timestamp	13 – 17	Timestamp
18 – 31	Date/Time	18 – 31	Date/Time	18 – 31	Date/Time
32 – 33	CME Info	32 – 33	CME Info	32 – 33	CME Info
34 – 35	Message Type	34 – 35	Message Type	34 – 35	Message Type
36 – 41	CME Info	36 – 41	CME Info	36 – 41	CME Info
42 – 49	Trading Date	42 – 49	Trading Date	42 – 49	Trading Date
50 – 69	Instrument	50 – 69	Instrument	50 – 69	Instrument
70	Trading Origin	70 – 81	Trade Quantity	70 – 81	Trade Quantity
71	Trading Mode	82	Locator Price	82	Decimal Locator Price
72 – 76	Blank spaces	83 – 100	Trade Price	83 – 100	Trade Price
77	Flag 1st Limit	101 – 116	Blocked Data	101 – 116	Blocked Data
78	Flag 2nd Limit	117 – 128	Total Quantity	117 – 128	Total Quantity
79	Flag 3rd Limit	129	Format Type	129	Format Type
80	Flag 4th Limit	130	Decimal Net	130	Decimal Locator Net
81	Flag 5th Limit	131 – 148	Net Change	131 – 148	Net Change
82	Flag 6th Limit	149	Cross Trade	149	Indicator Price
83 – 94	Buy Quantity	150	Last Trade	150 – 167	Highest Price
95 – 98	Number of Buy	151	Price Variation	168	Indicator Price
99	Decimal Buy	152 – 163	Blocked Data	169 – 186	Lowest Price
100 – 117	Buy Limit Price			187 – 188	Trade Trend
118	Decimal Sell			189	Cross Trade
119 – 136	Sell Limit Price			190	Last Trade
137 – 140	Number of Sell			191	Trade Origin
141 – 152	Sell Quantity			192	Price Variation
153 – 154	Blank spaces			193 – 208	Blocked Data
155 – 512	Repeated				

Table 1.2 Encoded Contracts and Dates

This table presents information about the futures contracts used in this study. The designated ticker symbols are the relevant ones for the electronic trading version of these futures. The dates represent the original time span of available data in the encoded RLC format. The size refers to the size of the encoded datasets.

Contract	Ticker Symbol	Dates	Size
T-note	ZN	01/20/2008 - 03/28/2009	58.10 GB
Corn	ZC	01/11/2008 - 03/21/2009	133.00 GB
Oil	CL	01/01/2008 - 04/18/2009	1.09 TB
Euro	6E	01/02/2008 - 10/02/2009	144.00 GB
Yen	6J	01/02/2008 - 10/02/2009	95.40 GB
Gold	GC	01/01/2008 - 04/18/2009	365.00 GB

Table 1.3 Trade Activity Summary

This table presents a summary of the overall trade activity in the futures contracts based on the CME Group Exchange Volume Report. “Volume” represents the total volume traded for the futures contract during 2009. “Electronic” represents the amount of volume that was electronically traded for the futures contract in 2009. “Daily volume” is the average volume for each trading day in 2009. All the values in this table represent trading of all expirations and both outright and combination trades (e.g. spreads) in a given contract.

Contract	Volume	Electronic	Daily Volume
T-note	189,852,019	95.18%	753,381
Corn	50,948,804	87.69%	202,179
Oil	137,428,494	92.25%	545,351
Euro	54,393,644	99.04%	215,848
Yen	22,749,569	98.15%	90,276
Gold	35,139,541	89.74%	139,442

Table 1.4 Contract Specifications

This table lists the contract specifications for each futures contract. DCM represents one of the four designated markets of the CME Group. Contract size, price quote, and tick size describe the relevant contract specifications for each futures contract.

Contracts	DCM	Contract Size	Price Quote	Tick Size
T-note	CBOT	One T-note	Points and halves of 1/32 of a point	One-half of one thirty-second (1/32) of one point
Corn	CBOT	5,000 bushels	Cents per bushel	1/4 of one cent per bushel
Oil	NYMEX	1,000 barrels	U.S. dollars and cents per barrel	\$0.01 per barrel
Euro	CME	125,000 euros	U.S. dollars and cents	\$.0001 per euro increments
Yen	CME	12,500,000 Japanese yen	U.S. dollars and cents	\$.000001 per Japanese yen increments
Gold	COMEX	100 troy ounces	U.S. dollars and cents per troy ounce	\$0.10 per troy ounce

CHAPTER 2: CHARACTERISTICS OF FIVE-DEEP DEPTH IN FUTURES MARKETS

2.1. Introduction

The market depth allocated in the limit order book holds both practical and theoretical importance. From a practical perspective, the distribution of liquidity across the levels of a limit order book affects the trading behavior and order submissions tactics of market participants. For example, if depth in the limit order book is shallow as opposed to deep, then trades with volumes surpassing the depth available at the best level are costlier to execute. Using limit order book data, the immediate price impact of a specific transaction size can be calculated. From a theoretical perspective, substantial research exists that models depth in relation with other variables, such as volatility and the bid-ask spread, to explain the microstructure of diverse markets. However, before the behavior of depth and its relation to other market factors can be analyzed, the fundamental characteristics of depth should be established.

The goal of this chapter is to establish the characteristics of the limit order book depth in the electronic U.S. futures markets. The characteristics of limit order book depth are known for several markets around the world, such as the Paris Bourse, Stockholm Stock Exchange, and Stock Exchange of Thailand.⁸ However, the characteristics of market depth for U.S. futures markets are unexplored in past research. This chapter examines the characteristics of depth in U.S. electronic futures markets by using an exchange proprietary database from the CME Group with five levels of depth.

⁸ See Biais, Hillion, and Spatt (1995), Niemeyer and Sandas (1995), and Visaltanachoti, Charoenwong, and Ding (2008).

In this chapter I explore the probability distributions of depth for all five levels of depth and the allocation of depth between the levels. This study contributes to the existing literature by documenting the characteristics of five-deep depth in U.S. electronic futures markets. In addition, the shape and symmetry of the limit order book across the six futures contracts employed here is also explored. A unique aspect of this study is the use of electronic high-frequency data, an examination of the individual depth messages, and the comparison of characteristics between the day and night trading sessions.

2.2. Literature Review

Recent technological improvements led to the existence of electronic limit order books, including the availability of depth data past the first level. Many exchanges around the world contain electronic limit order books, such as stock exchanges in Tokyo, London, Frankfurt, Australia, Hong Kong, Stockholm, Toronto, plus Euronext, the London International Financial Futures Exchange, and the Sydney Futures Exchange. Studies employing data from these exchanges examine the characteristics of depth along the limit order book.

One of the first articles to examine the characteristics of depth in the limit order book is Biais, Hillion, and Spatt (1995). Using stocks from the Paris Bourse, they find that depth at the best bid-ask quotes represent only a small portion of the overall depth in the limit order book. In addition, they find evidence to reject the equality of depth at all levels, although depth away from the best level does not vary significantly across the levels.

Visaltanachoti, Chaoenwong, and Ding (2008) study the liquidity distribution for equities on the Thailand stock exchange. They find that the first three levels of depth on both sides of the book are not significantly different. Similarly, Niemeyer and Sandas (1995) examine depth on the Stockholm Stock Exchange, rejecting the null hypothesis of equal means for depth across the limit order book. Another study on the characteristics of depth is carried out by Al-Suhaibani and Kryzanowski (2000) using the Saudi stock market. They document the smallest amount of depth at the best level and the largest amount of depth at the second level in their five-deep limit order book. Furthermore, they find evidence that depth is not equal across all five levels. However, after excluding the depth at the second level, they find that depth across the remaining four levels is equal. Thus, although the characteristics of depth are explored for various stock and international markets, the U.S. futures markets is an unexplored area of research for depth.

2.3. Data

One unique aspect of this dissertation is the data includes the first five levels of depth for U.S. futures markets. The six futures contracts employed in this research are the T-note, corn, oil, the euro, yen, and gold. The data is initially encoded in RLC format and then decoded as explained in Chapter 1. Table 2.1 lists the range of dates available for the decoded data. The data begins in January 2008 and spans through a portion of 2009 for each contract. The table also lists the number of depth (MA) message updates contained in each futures contract sample. When a depth characteristic changes (due to a change in the quoted price or to a change in any of the five depth levels), then this action generates a new message. Therefore, a larger number of messages is associated with more depth

updates. In particular, the euro futures contract shows the largest number of depth messages (495,558,768), whereas corn futures possess the smallest number (30,420,858). Also listed in Table 2.1 is the size of the decoded depth data set for each contract, ranging from 6.34 GB for corn to over 100 GB for euro futures.⁹

The depth messages only contain information concerning updated levels. For example, if the third depth level is the only updated level in a depth message, then the message only contains the updated price and depth size associated with the third level, with the other four levels left blank. Therefore, in order to populate all the levels for an update, the previous values for the other depth levels are used to complete the entire depth population. The resulting data set created contains the appropriate depth information for all five levels for each depth update.

Each of the MA depth messages updates the first, second, third, fourth, and/or fifth depth level in any combination. Table 2.2 shows the top fifteen combinations of depth updates and their respective frequencies in the data. For all the futures contracts, except oil, the top update by frequency is solely for the first depth level (“10000”). Figure 2.1 plots and compares the percentage of depth messages that involve any combination of the best depth (for example “10100”) and any combination of messages that omit the best depth (for example “00110”). The T-note and corn futures show approximately the same number of messages that involve the first level of depth relative to messages that exclude the first level of depth. For the euro and yen futures, the number of messages omitting the best depth is slightly larger, whereas for gold and oil futures the percentage of messages

⁹ In comparison to the size of the encoded data, the size of the decoded often is much smaller. For example, oil futures have an encoded size of 1.09 TB but a decoded size of 62.6 GB. This reduction in size is due to the large number of combination (spread) trades that are removed from the oil sample.

not involving the best depth are almost double those involving the best depth. Figure 2.1 shows that a major portion of the depth activity updates occurs at level two to five.

In this database, contracts are rolled over when trading volume in the first deferred contract exceeds volume in the nearby contract. Specifically, for all contract expirations present in the data, the sum of the trading volume is calculated over all days in the sample. The daily volume for each expiration month is examined and when the daily volume in the first deferred contract is larger than the nearby, the contract is rolled over. All of the ensuing analysis is carried out separately for the day and night periods.¹⁰

2.4. Methodology

First I examine the amount of time that elapses between market depth updates. The use of high-frequency data time-stamped to the nearest centi-second allows for the computation of the duration between sequential depth updates during the day and night. The following research hypothesis is tested concerning duration of depth:

Research hypothesis 1: A difference in duration exists between the day and night periods.

The second topic I examine is the individual depth levels on each side of the book. There are two sides of the limit order book, the bid (buy) side and the ask (sell) side. For each depth level, data exists on each side of the book.¹¹ From an individual depth level perspective, the amount of depth is quantified as the number of contracts available for the first, second, third, fourth, and fifth level of depth, on each side of the limit order book. Summary statistics are calculated for each of these levels of depth.

¹⁰ The day period corresponds to the traditional open outcry hours, whereas the night period contains the hours outside of the open outcry period.

¹¹ If a sequential price does not have any depth then the database uses the next price that includes depth for the five-deep order level data.

This is followed by an examination of the aggregate depth levels. These aggregate levels can be quantified as one of the following:

$$Level\ Depth_i = Depth_{Bid\ i} + Depth_{Ask\ i},\ i = 1, 2, 3, 4, 5 \quad (2.1)$$

$$Bid\ Depth = \sum_{i=1}^5 Depth_{Bid\ i} \text{ and } Ask\ Depth = \sum_{i=1}^5 Depth_{Ask\ i} \quad (2.2)$$

$$Total\ Depth = \sum_{i=1}^5 Depth_{Bid\ i} + \sum_{i=1}^5 Depth_{Ask\ i} \quad (2.3)$$

Equation 2.1 represents the depth on both sides of the book combined at each depth level. Equation 2.2 represents the total bid and ask depth on each side of the book for all five levels. Equation 2.3 represents the overall depth at all levels on both sides of the book combined.

The symmetry of the bid and ask sides of the limit order book is examined for each level during the day and night hours. The associated research hypothesis is:
Research hypothesis 2: The limit order book is not symmetrical at each depth level.

In order to examine the equality of depth across levels, the following research hypotheses are proposed:

Research hypothesis 3: Depth is not equal across all depth levels.

Research hypothesis 4: Depth is not equal across all depth levels excluding the best level.

Research hypothesis 5: Depth is not equal between pairs of levels.

In order to compare depth during the day and night, the following research hypotheses are proposed:

Research hypothesis 6: Best depth is not equal across the day and night periods.

Research hypothesis 7: Total depth is not equal across the day and night periods.

2.5. Results

2.5.1. Duration and Summary

Table 2.3 presents the duration results for the day and night sessions. The table shows the mean duration for the day and night for each of the six futures contracts, along with the t-statistic for the difference in means between the day and night periods. For the T-note, corn, oil, and gold futures, the mean duration, or the time elapsed in seconds between depth message updates, is smaller during the day than during the night, showing that the depth updates occur more often during the day than the night. The difference in means between the day and night duration is positive and statistically significant for the T-note, corn, oil, and gold futures. However, for the euro and yen futures no statistical difference in the duration exists between the day and night.

Table 2.4 provides the summary statistics for each depth level on each side of the limit order book for both the day and night trading. The results illustrate that the depth at level one, at both the bid and ask sides, are typically smaller than the depth at levels two and three. For instance, the bid depth for the T-note futures at level one averages 404.44, whereas the bid depth at level two is twice as large at 900.86. Moreover, the depth peaks at level three and then slowly decreases at levels four and five. A similar trend occurs for the other contracts and for both the day and night sessions. It is evident from the table that the night depth is smaller than the depth during the day at each level.

Table 2.5 presents the summary statistics of the aggregate bid plus ask depth measures. The aggregate depth measures increase along the limit order book from level one to level three. For example, the average aggregate depth at level one for the euro

futures is 42.10, whereas the depth at levels two and three are 111.28 and 160.93, respectively.

Table 2.6 shows a summary of additional depth related variables. The best depth orders, total depth orders, the ratio of best depth to best orders, and the ratio of total depth to total orders are larger for the day than for the night for all futures contracts. The depth location is closer to the best level (smaller value) during the day session than the night.

The distributions for best depth and total depth for the day and night sessions are illustrated in Figures 2.2 through 2.7. Across all futures, the distributions of the best depth and total depth are more widely dispersed over the night session compared to the day session.

Table 2.7 presents the comparison of moments across the contracts for the day and night sessions. The standardized mean during the day is larger than the night mean. The best depth and total depth are more skewed during the night compared to the day as shown by the larger skewness. On average, the kurtosis is also larger for the night than the day.

2.5.2. Symmetry and Equality

The symmetry of the depth levels is described in Table 2.8. During the day, the T-note, euro, yen, and gold futures are symmetric between the bid and ask side of the book at all five depth levels. The exceptions are corn futures at levels two through five and oil futures at levels one and two. During the night trading, the limit order book is symmetric at all levels for all contracts except for corn futures at levels one and two.

The single-factor within-subjects analysis of variance test results for all five depths are provided in Table 2.9. The results show that the null hypothesis of equality

across all five depth levels is rejected at the one percent level for all futures for both the day and night sessions. Rejection of the null hypothesis for equality of all depths is consistent with Biais, Hillion, and Spatt (1995) who find a similar result for 33 out of 40 stocks traded on the Paris Bourse. However, this result is contrary to Visaltanachoti, Charoenwong, and Ding (2008) who fail to reject the null hypothesis of equality for stocks traded on the Stock Exchange of Thailand. Table 2.9 also presents the results for the equality of depth levels excluding the best level. The hypothesis of equality between the levels is rejected for all contracts during the day and night except for T-note futures during the day. Overall, this result is in stark contrast to both Biais, Hillion, and Spatt (1995) and Visaltanachoti, Charoenwong, and Ding (2008), since they both find a lack of evidence to reject the null of equality of all depth levels when the first depth level is excluded.

Table 2.10 shows the results for the pair-wise comparison of the equality of depth levels. The majority of the differences in depth level pairs are statistically significant for both the day and night sessions across contracts. The implication is that comparing any two of the five depth levels at a time shows the depth is not equal. Exceptions occur for the T-note and corn futures. For instance, Panel A for the T-note futures shows that the depth at level two and three is equal.

Table 2.11 presents the depth comparison between the day and night periods. The larger difference of the day over the night session is statistically significant at the one percent level for both the best depth and total depth for all six futures contracts.

Figures 2.8 through 2.13 depict the cumulative depth up to each of the five levels. The figures show that the differences in available depth during the day and night sessions

is large. Figures 2.14 through 2.19 show the graphical representation of the shape of the limit order book for each futures contract. For instance, Figure 2.16 for oil futures and Figure 2.19 for gold futures both show an increase in depth at each level away from the best level. This result is similar to Biais, Hillion, and Spatt (1995), who find the same limit order book pattern for stocks on the Paris Bourse. However, the limit order book for the other futures contracts examined here provide a strikingly different pattern. Figure 2.17 for the euro futures and Figure 2.18 for the yen futures show a decrease in the amount of depth available at the fifth level relative to the fourth level. The T-note futures and corn futures in Figures 2.14 and 2.15 also show less depth at the fifth level relative to the fourth.

2.6. Conclusion

To summarize, this chapter presents the characteristics of the five levels of depth for six U.S. futures contracts. The analysis shows that the duration between depth updates is smaller during the day than at night. The results also show that depth during the day is larger than depth during the night. The distributions of the total depth during the night is also more dispersed and skewed than during the day. The depth is not equal across all levels. However, the limit order book is generally symmetric between the bid and ask side at each level. This analysis of market depth presents new insights into the characteristics of depth in U.S. futures markets. Specifically, the analysis reveals the difference in depth characteristics between the day and night periods.

Table 2.1: Decoded Contracts and Dates

This table shows the characteristics of the decoded data sets for the six futures contracts. “Days” represents the number of trade dates available for each contract after the removal of missing data. “Messages” reflects the number of depth updates. “Size” represents the decoded size of the depth dataset.

Futures Contract	Date Range	Days	Messages	Size
T-note	01/28/2008 – 03/13/2009	214	174,118,480	37.50 GB
Corn	01/14/2008 – 03/20/2009	285	30,420,858	6.34 GB
Oil	01/02/2008 – 04/17/2009	327	308,238,184	62.60 GB
Euro	01/03/2008 – 10/02/2009	398	495,558,768	103.00 GB
Yen	01/03/2008 – 10/02/2009	441	325,195,385	67.40 GB
Gold	01/02/2008 – 04/17/2009	307	152,281,837	31.20 GB

Table 2.2: Depth Flag Updates

This table presents the fifteen depth update flags with the largest frequency of occurrence in the data. The panels show these results for each futures contract. “Flags” represents the different depth update flags. Each of the five character positions represents the first, second, third, fourth, and fifth level sequentially. A value of 1 represents a depth update, and a value of 0 states that no update to the depth occurs. “Count” is the number of times the particular depth update flag is present in the data. “Percent” is the share of the presented flags relative to the total number of depth updates. The “other” designation in the Flags column combines the remaining flag updates not otherwise listed.

Flags	Count	Percent
Panel A: T-Note Futures		
10000	45,062,577	25.88
01000	28,573,022	16.41
00100	14,248,311	8.18
10100	11,149,758	6.40
01100	10,171,893	5.84
11000	8,203,883	4.71
00001	8,014,641	4.60
00110	7,807,299	4.48
00010	7,414,234	4.26
10010	6,152,044	3.53
00011	5,652,230	3.25
11111	3,917,541	2.25
11100	3,004,626	1.73
10001	2,305,573	1.32
01010	1,890,444	1.09
Other	10,550,404	6.00
Panel B: Corn Futures		
10000	8,943,324	29.40
01000	3,977,845	13.08
01100	3,071,837	10.10
11111	2,441,434	8.03
11000	2,329,984	7.66
00100	2,086,886	6.86
00001	1,502,356	4.94
00110	1,383,515	4.55
00010	1,350,163	4.44
00011	742,024	2.44
10100	621,768	2.04
01010	461,051	1.52
11100	304,271	1.00
00101	176,744	0.58
01111	156,833	0.52
Other	870,823	3.00

Table 2.2 (Continued)

Panel C: Oil Futures		
11111	44,098,036	14.31
00001	41,652,507	13.51
00010	29,566,108	9.59
01000	26,524,859	8.61
00100	26,385,995	8.56
10000	25,766,313	8.36
00011	19,389,974	6.29
00110	12,913,859	4.19
01111	11,238,125	3.65
00111	9,651,001	3.13
01100	8,665,130	2.81
00101	6,369,035	2.07
11000	5,233,053	1.70
01010	4,761,892	1.54
01001	3,812,907	1.24
Other	28,664,926	9.00
Panel D: Euro Futures		
10000	122,101,492	24.64
01000	68,624,115	13.85
00100	64,526,176	13.02
00010	53,161,068	10.73
00001	44,810,800	9.04
10001	38,964,371	7.86
11111	26,331,667	5.31
00110	14,029,472	2.83
01100	11,695,685	2.36
10010	11,234,824	2.27
00011	9,854,904	1.99
10100	7,533,604	1.52
11000	5,603,858	1.13
01010	2,522,784	0.51
01001	2,370,842	0.48
Other	10,284,333	2.00

Table 2.2 (Continued)

Panel E: Yen Futures		
10000	78,236,054	24.06
01000	42,819,830	13.17
00100	41,319,047	12.71
00010	33,326,574	10.25
00001	26,112,074	8.03
10010	24,230,737	7.45
11111	20,233,574	6.22
10001	14,413,108	4.43
00110	6,700,092	2.06
01100	6,597,410	2.03
10100	6,367,980	1.96
01001	4,974,494	1.53
00011	4,549,918	1.40
11000	3,418,166	1.05
01010	1,932,193	0.59
Other	9,964,134	3.00
Panel F: Gold Futures		
10000	26,154,578	17.18
00001	23,317,481	15.31
01000	20,249,464	13.30
11111	16,673,950	10.95
00100	16,114,519	10.58
00010	13,208,512	8.67
00011	8,925,438	5.86
00110	4,972,843	3.27
11000	3,885,572	2.55
01100	3,644,971	2.39
01111	2,884,057	1.89
00111	2,257,822	1.48
00101	1,545,208	1.01
10100	1,497,178	0.98
01010	1,447,344	0.95
Other	5,502,900	4.00

Table 2.3 Duration Day and Night

This table presents results for the difference in duration between the day and night. The duration is calculated as the amount of time in seconds that elapses between depth message updates.

	Mean Day	Mean Night	t statistic	Prob
T-note	0.09	0.36	8.91	<.0001
Corn	0.27	5.24	16.05	<.0001
Oil	0.07	0.31	10.38	<.0001
Euro	0.08	0.16	0.92	0.3584
Yen	0.12	0.22	1.07	0.2857
Gold	0.14	0.43	3.69	0.0002

Table 2.4 Individual Depth Level Summary

This table presents the summary statistics for the depth at each depth level on the bid and ask side of the limit order book. The depth is summarized separately for the day and the night, using five minute intervals.

Variable	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel A: T-note Day							
Bid Depth 1	404.44	392.28	221.62	0.92	3.05	101.61	777.95
Bid Depth 2	900.86	908.83	488.35	0.30	-0.46	190.13	1718.80
Bid Depth 3	951.35	948.47	515.71	0.40	-0.19	204.23	1826.89
Bid Depth 4	921.24	930.39	505.72	0.32	-0.43	192.41	1768.59
Bid Depth 5	925.73	950.35	525.71	0.22	-0.63	162.78	1776.52
Ask Depth 1	400.85	388.09	216.01	0.70	1.01	100.35	775.32
Ask Depth 2	888.82	895.56	476.37	0.25	-0.58	189.62	1682.89
Ask Depth 3	935.96	940.31	498.03	0.32	-0.33	201.55	1768.41
Ask Depth 4	903.47	910.08	492.23	0.31	-0.41	186.62	1723.20
Ask Depth 5	910.88	929.60	517.05	0.24	-0.58	158.30	1751.48
Panel B: T-note Night							
Bid Depth 1	187.59	147.94	156.51	2.75	23.72	28.48	475.81
Bid Depth 2	395.65	322.60	304.12	1.90	14.30	55.79	981.01
Bid Depth 3	453.34	374.04	333.75	1.20	1.90	67.07	1087.75
Bid Depth 4	469.47	386.55	350.06	1.20	1.93	67.51	1145.25
Bid Depth 5	470.22	386.09	354.11	1.15	1.56	66.49	1145.03
Ask Depth 1	186.92	148.64	157.07	2.74	19.27	29.15	473.11
Ask Depth 2	388.85	321.61	300.19	1.73	8.08	56.51	964.96
Ask Depth 3	447.28	371.45	333.46	1.30	2.69	68.67	1085.93
Ask Depth 4	462.65	374.64	359.49	1.67	6.49	70.55	1131.19
Ask Depth 5	461.41	376.07	355.02	1.40	4.43	67.02	1124.82
Panel C: Corn Day							
Bid Depth 1	33.69	28.06	27.66	15.55	554.21	12.22	71.11
Bid Depth 2	62.37	52.56	43.13	4.76	65.03	20.71	131.74
Bid Depth 3	66.89	56.79	45.43	3.39	29.54	20.85	144.24
Bid Depth 4	62.92	52.00	45.19	2.95	22.17	16.72	142.88
Bid Depth 5	63.35	51.21	48.86	3.32	26.69	16.22	148.00
Ask Depth 1	32.94	27.44	28.32	15.30	465.47	12.36	67.39
Ask Depth 2	59.41	50.39	39.35	4.27	48.56	21.19	126.33
Ask Depth 3	62.32	53.17	40.77	3.22	22.23	21.13	132.75
Ask Depth 4	57.27	47.59	41.18	4.15	45.38	17.24	128.40
Ask Depth 5	57.70	47.16	42.42	3.62	33.60	16.61	134.06

Table 2.4 (Continued)

Variable	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel D: Corn Night							
Bid Depth 1	10.82	5.92	17.41	8.10	145.94	1.13	35.14
Bid Depth 2	17.67	9.17	29.45	7.17	90.80	1.33	58.83
Bid Depth 3	20.99	11.00	35.18	6.32	61.21	1.50	69.00
Bid Depth 4	22.83	12.00	38.95	6.91	74.86	1.63	74.22
Bid Depth 5	24.35	13.08	40.28	6.88	76.55	1.96	79.00
Ask Depth 1	12.54	6.47	23.71	9.89	168.03	1.21	41.29
Ask Depth 2	20.45	9.71	43.71	9.41	124.49	1.33	66.05
Ask Depth 3	22.86	11.31	40.46	7.63	96.12	1.47	79.12
Ask Depth 4	24.22	12.52	40.18	7.10	87.57	1.67	83.51
Ask Depth 5	26.09	14.00	38.05	4.68	36.23	1.80	93.07
Panel E: Oil Day							
Bid Depth 1	4.85	4.56	1.57	1.12	2.28	2.85	7.77
Bid Depth 2	7.90	7.29	3.27	1.05	1.83	3.77	14.08
Bid Depth 3	10.64	9.56	5.09	1.06	1.23	4.49	20.52
Bid Depth 4	12.91	11.34	6.58	1.05	0.91	5.21	26.11
Bid Depth 5	14.95	13.23	7.37	0.97	0.66	5.97	29.71
Ask Depth 1	4.70	4.44	1.52	1.05	1.97	2.74	7.51
Ask Depth 2	7.54	6.96	3.08	1.11	2.45	3.67	13.30
Ask Depth 3	10.35	9.29	4.91	1.17	2.58	4.43	19.74
Ask Depth 4	12.86	11.27	6.54	1.05	0.85	5.17	25.97
Ask Depth 5	15.11	13.50	7.32	1.00	0.78	6.13	29.88
Panel F: Oil Night							
Bid Depth 1	3.23	2.51	2.91	9.13	201.79	1.15	7.39
Bid Depth 2	4.42	3.28	4.34	8.44	204.85	1.26	10.99
Bid Depth 3	5.12	3.69	4.98	5.25	61.05	1.36	13.59
Bid Depth 4	5.53	3.94	5.48	5.99	98.83	1.42	14.89
Bid Depth 5	5.92	4.17	5.83	4.74	51.58	1.50	16.23
Ask Depth 1	3.18	2.44	2.82	7.50	140.22	1.12	7.44
Ask Depth 2	4.37	3.18	4.58	8.34	149.55	1.24	11.00
Ask Depth 3	5.13	3.68	5.27	6.96	117.71	1.33	13.60
Ask Depth 4	5.62	4.05	5.52	4.88	53.09	1.42	15.30
Ask Depth 5	6.03	4.27	5.84	3.87	28.59	1.50	16.67

Table 2.4 (Continued)

Variable	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel G: Euro Day							
Bid Depth 1	21.10	18.95	11.41	0.91	1.29	6.65	41.62
Bid Depth 2	55.56	51.12	30.61	0.54	-0.30	15.17	109.45
Bid Depth 3	80.39	76.46	40.59	0.30	-0.87	24.11	147.66
Bid Depth 4	85.18	79.69	40.04	0.32	-0.82	29.71	152.20
Bid Depth 5	77.57	72.47	34.63	0.37	-0.64	29.88	135.72
Ask Depth 1	21.00	18.78	11.35	0.94	1.98	6.67	41.44
Ask Depth 2	55.72	51.24	30.83	0.52	-0.48	15.16	109.74
Ask Depth 3	80.53	75.63	41.00	0.32	-0.90	24.16	149.13
Ask Depth 4	85.09	80.05	39.83	0.31	-0.86	29.83	151.58
Ask Depth 5	78.09	73.14	34.96	0.36	-0.66	29.71	136.25
Panel H: Euro Night							
Bid Depth 1	13.48	10.90	9.37	2.04	17.74	3.57	31.41
Bid Depth 2	34.37	28.13	23.58	1.11	2.04	7.57	78.72
Bid Depth 3	48.94	43.55	29.34	0.80	0.79	11.87	101.61
Bid Depth 4	50.07	44.47	28.26	0.83	0.95	13.79	101.87
Bid Depth 5	42.08	36.69	23.80	0.98	1.19	12.36	86.99
Ask Depth 1	13.31	10.82	9.12	1.49	3.65	3.47	31.04
Ask Depth 2	34.13	27.95	23.61	1.14	2.81	7.30	78.22
Ask Depth 3	49.22	43.35	30.16	0.85	0.99	11.58	103.83
Ask Depth 4	50.22	44.56	28.49	0.83	1.00	13.50	102.52
Ask Depth 5	42.05	36.63	24.04	1.10	2.86	12.14	87.23
Panel I: Yen Day							
Bid Depth 1	18.99	14.97	12.50	1.37	2.91	5.46	43.50
Bid Depth 2	50.22	37.05	35.97	0.91	-0.12	10.55	119.98
Bid Depth 3	72.92	55.69	48.28	0.69	-0.65	16.25	161.96
Bid Depth 4	72.18	55.93	43.78	0.72	-0.61	21.70	154.37
Bid Depth 5	61.27	48.98	35.05	0.74	-0.42	21.07	125.77
Ask Depth 1	19.02	15.02	12.55	1.39	2.91	5.50	43.78
Ask Depth 2	50.47	37.07	36.37	0.98	0.20	10.57	121.39
Ask Depth 3	71.85	54.47	47.33	0.70	-0.60	16.28	159.00
Ask Depth 4	71.35	55.91	42.51	0.69	-0.66	21.65	149.78
Ask Depth 5	61.66	49.76	35.46	0.77	-0.31	21.20	127.94

Table 2.4 (Continued)

Variable	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel J: Yen Night							
Bid Depth 1	13.53	10.03	10.71	2.09	6.64	3.55	35.37
Bid Depth 2	35.23	24.23	28.55	1.20	1.12	6.46	93.33
Bid Depth 3	46.82	34.31	34.00	0.93	0.08	9.11	113.48
Bid Depth 4	44.14	32.66	30.74	0.99	0.19	9.74	105.11
Bid Depth 5	38.04	27.66	27.06	0.99	0.25	8.24	90.41
Ask Depth 1	13.59	10.15	10.72	2.17	9.02	3.57	35.63
Ask Depth 2	35.36	24.44	28.70	1.20	0.90	6.41	94.05
Ask Depth 3	46.60	33.77	34.24	0.95	0.09	9.07	113.68
Ask Depth 4	43.80	32.34	30.49	0.97	0.18	9.50	104.08
Ask Depth 5	38.05	27.74	26.95	0.98	0.23	8.13	90.79
Panel K: Gold Day							
Bid Depth 1	6.21	5.83	2.50	1.14	2.43	3.03	10.75
Bid Depth 2	10.00	9.61	4.74	1.22	6.42	3.93	18.20
Bid Depth 3	11.56	10.98	5.63	1.20	5.59	4.31	21.46
Bid Depth 4	12.22	11.38	6.02	1.22	3.94	4.59	23.02
Bid Depth 5	12.84	11.90	6.29	1.52	7.97	4.90	23.94
Ask Depth 1	6.19	5.80	2.50	1.15	2.46	3.01	10.75
Ask Depth 2	9.98	9.53	4.71	1.01	2.58	3.89	18.15
Ask Depth 3	11.51	11.01	5.57	1.02	2.78	4.23	21.21
Ask Depth 4	12.14	11.36	5.98	1.16	2.78	4.44	22.95
Ask Depth 5	12.75	11.89	6.30	1.30	3.56	4.75	24.06
Panel L: Gold Night							
Bid Depth 1	4.29	3.60	2.88	3.92	36.39	1.56	9.17
Bid Depth 2	6.05	4.89	4.76	5.61	105.02	1.83	13.75
Bid Depth 3	7.40	5.97	5.79	4.14	51.77	2.02	17.30
Bid Depth 4	8.41	6.75	6.50	3.64	40.97	2.16	19.76
Bid Depth 5	8.99	7.24	6.97	3.70	34.15	2.31	20.98
Ask Depth 1	4.33	3.61	2.93	3.64	30.22	1.56	9.40
Ask Depth 2	6.11	4.89	4.96	6.18	118.12	1.83	14.16
Ask Depth 3	7.52	6.02	5.94	3.45	26.42	2.01	17.86
Ask Depth 4	8.53	6.78	6.79	3.35	24.21	2.17	20.34
Ask Depth 5	9.11	7.21	7.29	3.47	27.83	2.33	21.82

Table 2.5 Aggregate Depth Level Summary

This table presents the summary statistics for several aggregate depth measures. The level depth is the sum of the depth at the ask and bid of that level. The bid (ask) depth is the sum of all five depth levels on the bid (ask) side of the limit order book. Total depth is the summation of depth at all five levels on both sides of the limit order book. The depth is summarized separately for the day and the night, using five minute intervals.

Variable	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel A: T-note Day							
Level Depth 1	805.29	807.93	404.63	0.35	-0.10	210.96	1469.01
Level Depth 2	1789.68	1831.36	935.03	0.13	-0.85	395.03	3324.72
Level Depth 3	1887.31	1914.18	980.61	0.22	-0.58	428.86	3502.37
Level Depth 4	1824.72	1857.39	959.91	0.13	-0.85	404.93	3376.55
Level Depth 5	1836.61	1902.14	1005.35	0.06	-1.01	346.72	3414.17
Bid Depth	4103.63	4209.68	2155.98	0.13	-0.89	885.39	7675.23
Ask Depth	4039.98	4139.78	2101.87	0.10	-0.92	881.00	7502.04
Total Depth	8143.61	8394.51	4162.99	0.02	-1.04	1842.43	14838.96
Panel B: T-note Night							
Level Depth 1	374.51	313.38	277.39	1.92	9.42	70.50	898.53
Level Depth 2	784.50	661.69	562.62	1.31	3.59	131.85	1860.96
Level Depth 3	900.62	764.37	624.32	1.03	1.05	159.71	2091.59
Level Depth 4	932.12	785.54	656.30	1.09	1.34	169.04	2196.13
Level Depth 5	931.62	787.97	654.56	1.01	0.93	166.37	2185.78
Bid Depth	1976.27	1682.76	1366.05	1.00	0.93	348.00	4591.71
Ask Depth	1947.10	1650.09	1361.68	1.07	1.17	357.09	4572.80
Total Depth	3923.36	3392.56	2613.49	0.93	0.63	761.79	8896.26
Panel C: Corn Day							
Level Depth 1	66.63	57.48	43.97	7.99	154.20	26.97	131.25
Level Depth 2	121.78	108.20	66.22	2.54	17.79	47.48	237.39
Level Depth 3	129.21	116.38	66.32	1.83	8.13	49.62	247.79
Level Depth 4	120.19	107.29	65.56	2.04	11.19	42.62	237.24
Level Depth 5	121.05	107.04	67.04	2.07	10.94	42.92	241.96
Bid Depth	289.22	251.40	167.60	1.72	5.09	98.65	598.15
Ask Depth	269.65	237.12	147.52	1.78	5.40	102.83	547.68
Total Depth	558.87	515.92	253.75	0.98	1.14	228.52	1036.09

Table 2.5 (Continued)

Variable	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel D: Corn Night							
Level Depth 1	23.36	14.93	30.36	6.66	82.35	4.00	67.86
Level Depth 2	38.12	24.00	53.49	6.55	65.78	5.58	111.95
Level Depth 3	43.85	29.00	53.05	5.01	41.18	6.92	126.57
Level Depth 4	47.04	32.00	55.09	4.99	41.41	7.29	133.45
Level Depth 5	50.44	35.20	54.57	4.29	31.02	8.40	140.50
Bid Depth	96.65	65.80	105.50	3.73	20.47	16.71	279.06
Ask Depth	106.16	70.93	119.71	3.96	24.15	17.30	315.16
Total Depth	202.80	160.67	157.85	2.84	11.73	60.67	489.50
Panel E: Oil Day							
Level Depth 1	9.55	9.09	2.76	0.83	0.76	5.91	14.72
Level Depth 2	15.45	14.39	5.81	0.80	0.52	7.87	26.38
Level Depth 3	21.00	19.04	9.29	0.87	0.44	9.43	38.84
Level Depth 4	25.78	22.64	12.43	0.95	0.45	10.98	50.94
Level Depth 5	30.06	26.93	13.88	0.88	0.33	12.76	58.26
Bid Depth	51.26	46.61	22.52	0.88	0.40	23.36	95.42
Ask Depth	50.58	46.01	22.06	0.90	0.49	23.21	94.20
Total Depth	101.83	92.79	42.33	0.80	0.08	48.53	185.91
Panel F: Oil Night							
Level Depth 1	6.41	5.35	4.32	5.41	72.84	2.67	13.34
Level Depth 2	8.79	7.00	6.75	5.11	65.58	3.07	20.27
Level Depth 3	10.25	7.97	7.98	3.73	32.12	3.31	24.93
Level Depth 4	11.15	8.64	8.74	3.36	25.10	3.50	27.56
Level Depth 5	11.95	9.12	9.35	2.85	14.77	3.71	30.11
Bid Depth	24.22	18.81	18.24	3.01	16.37	8.17	59.09
Ask Depth	24.33	18.76	18.59	2.85	13.62	8.04	60.27
Total Depth	48.55	39.92	30.19	2.15	6.65	19.15	108.33

Table 2.5 (Continued)

Variable	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel G: Euro Day							
Level Depth 1	42.10	38.26	21.65	0.61	-0.24	13.68	81.08
Level Depth 2	111.28	103.64	59.90	0.43	-0.74	31.48	216.39
Level Depth 3	160.93	153.22	79.99	0.23	-1.10	49.71	291.81
Level Depth 4	170.27	159.85	78.13	0.23	-1.08	61.14	298.25
Level Depth 5	155.67	146.27	67.53	0.23	-1.03	60.82	266.26
Bid Depth	319.81	299.83	150.84	0.26	-1.06	111.15	570.67
Ask Depth	320.44	300.68	151.55	0.26	-1.07	111.13	576.26
Total Depth	640.25	601.37	298.48	0.21	-1.17	226.45	1135.22
Panel H: Euro Night							
Level Depth 1	26.79	22.38	16.95	1.33	3.44	8.15	59.98
Level Depth 2	68.50	57.01	45.09	0.99	0.88	17.13	152.44
Level Depth 3	98.16	87.54	57.59	0.69	-0.08	25.07	201.55
Level Depth 4	100.28	89.70	54.79	0.69	-0.08	28.71	200.72
Level Depth 5	84.13	73.52	45.50	0.84	0.42	26.29	170.04
Bid Depth	188.93	167.24	106.41	0.78	0.18	55.26	385.05
Ask Depth	188.93	165.97	107.58	0.79	0.21	54.06	386.33
Total Depth	377.86	334.65	210.18	0.73	-0.06	111.65	764.11
Panel I: Yen Day							
Level Depth 1	38.01	30.14	23.80	1.05	0.62	11.33	85.43
Level Depth 2	100.68	74.04	70.83	0.85	-0.38	21.72	237.92
Level Depth 3	144.77	109.52	94.58	0.65	-0.82	33.53	319.35
Level Depth 4	143.53	111.38	85.38	0.67	-0.77	44.15	302.47
Level Depth 5	122.93	98.22	69.29	0.68	-0.67	43.57	252.14
Bid Depth	275.57	211.16	170.06	0.68	-0.79	80.15	595.85
Ask Depth	274.35	209.96	168.55	0.69	-0.75	79.83	591.31
Total Depth	549.92	419.56	336.86	0.67	-0.84	161.77	1188.86

Table 2.5 (Continued)

Variable	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel J: Yen Night							
Level Depth 1	27.11	20.59	19.39	1.67	4.06	8.31	67.78
Level Depth 2	70.60	48.33	55.53	1.12	0.48	14.87	184.08
Level Depth 3	93.42	67.27	67.19	0.91	-0.16	19.62	225.11
Level Depth 4	87.94	64.29	60.13	0.95	-0.05	20.65	207.30
Level Depth 5	76.10	55.01	52.72	0.91	-0.17	17.92	177.85
Bid Depth	177.76	126.88	124.06	0.96	-0.05	43.47	424.28
Ask Depth	177.41	126.38	124.07	0.97	-0.03	42.91	425.17
Total Depth	355.17	251.34	246.49	0.96	-0.11	88.73	846.51
Panel K: Gold Day							
Level Depth 1	12.40	11.85	4.52	0.77	0.72	6.42	20.48
Level Depth 2	19.98	19.65	8.61	0.61	0.61	8.43	34.41
Level Depth 3	23.08	22.64	9.98	0.52	0.23	9.30	39.90
Level Depth 4	24.36	23.52	10.42	0.59	0.25	9.90	42.55
Level Depth 5	25.59	24.68	10.68	0.67	0.91	10.57	44.24
Bid Depth	52.82	51.07	22.78	0.66	0.40	21.94	92.86
Ask Depth	52.57	50.97	22.74	0.69	0.52	21.46	92.44
Total Depth	105.40	104.48	41.22	0.30	-0.71	46.50	175.19
Panel L: Gold Night							
Level Depth 1	8.62	7.59	4.53	2.30	11.95	3.68	16.88
Level Depth 2	12.17	10.49	7.43	3.51	40.74	4.49	25.13
Level Depth 3	14.92	12.94	9.05	2.19	12.95	5.01	31.26
Level Depth 4	16.94	14.76	10.27	1.96	10.10	5.49	35.44
Level Depth 5	18.10	15.67	11.00	2.07	10.35	5.90	37.77
Bid Depth	35.15	30.13	21.33	1.91	6.91	11.93	74.34
Ask Depth	35.59	30.39	22.20	2.02	7.34	11.89	76.58
Total Depth	70.74	64.22	34.80	1.11	1.72	27.94	135.64

Table 2.6 Additional Depth Summary

This table presents the summary statistics for several additional depth measures. Best depth orders is the quantity of limit orders at the best level on both sides of the book. Total depth orders is the quantity of limit orders across all five levels on both sides of the book. Best depth/best orders is the ratio of depth at the best level to the number of limit orders at the best level. Total depth/total orders is the ratio of the depth across all five levels to the number of limit orders across the five levels. Depth location represents where the depth is positioned along the book.

Variable	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel A: T-note Day							
Best Depth Orders	57.59	56.03	21.21	0.44	0.23	26.18	95.27
Total Depth Orders	491.83	503.14	174.66	-0.09	-0.73	208.46	767.87
Best Depth/Best Orders	13.77	13.42	4.88	0.85	2.83	6.31	22.17
Total Depth/Total Orders	15.78	16.30	5.00	0.15	0.13	7.59	24.14
Depth Location	3.24	3.25	0.12	-0.31	0.74	3.02	3.42
Panel B: T-note Night							
Best Depth Orders	20.50	16.40	13.52	1.66	4.09	6.34	47.34
Total Depth Orders	203.88	177.56	114.53	1.10	1.42	64.44	420.92
Best Depth/Best Orders	19.58	17.04	11.29	3.05	24.11	7.60	39.61
Total Depth/Total Orders	18.79	17.89	7.06	1.32	6.49	8.94	31.47
Depth Location	3.31	3.32	0.21	-0.16	0.30	2.96	3.65
Panel C: Corn Day							
Best Depth Orders	13.56	12.51	5.38	1.72	12.36	6.96	23.61
Total Depth Orders	94.53	87.68	35.97	0.76	0.32	46.94	161.77
Best Depth/Best Orders	5.16	4.54	2.40	3.52	44.99	2.69	9.29
Total Depth/Total Orders	6.16	5.54	2.51	1.83	10.27	3.29	10.84
Depth Location	3.18	3.18	0.21	-0.52	4.49	2.86	3.50
Panel D: Corn Night							
Best Depth Orders	4.86	4.00	4.85	13.47	283.12	2.08	9.44
Total Depth Orders	36.23	31.66	23.72	5.56	46.75	17.08	64.62
Best Depth/Best Orders	4.93	3.54	5.04	5.71	69.90	1.29	12.90
Total Depth/Total Orders	5.63	4.86	3.00	2.52	10.62	2.64	10.96
Depth Location	3.31	3.31	0.45	-0.14	0.24	2.54	4.04

Table 2.6 (Continued)

Variable	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel E: Oil Day							
Best Depth Orders	5.07	4.84	1.36	1.00	1.28	3.33	7.70
Total Depth Orders	56.94	53.43	22.58	0.53	-0.54	27.18	98.44
Best Depth/Best Orders	1.93	1.86	0.47	1.01	1.56	1.32	2.81
Total Depth/Total Orders	1.81	1.77	0.36	0.96	1.86	1.32	2.45
Depth Location	3.48	3.48	0.13	-0.19	0.37	3.26	3.69
Panel F: Oil Night							
Best Depth Orders	3.08	2.88	0.86	2.35	18.34	2.11	4.73
Total Depth Orders	23.28	20.05	11.34	2.43	8.42	12.85	44.76
Best Depth/Best Orders	2.11	1.74	1.39	6.22	90.21	1.05	4.26
Total Depth/Total Orders	2.11	1.83	1.01	3.10	17.94	1.20	3.97
Depth Location	3.23	3.25	0.27	-0.52	1.91	2.76	3.63
Panel G: Euro Day							
Best Depth Orders	18.93	17.82	8.51	0.83	0.61	7.19	35.58
Total Depth Orders	188.10	181.30	80.26	0.66	0.37	73.20	341.85
Best Depth/Best Orders	2.26	1.97	0.87	0.98	1.08	1.29	3.80
Total Depth/Total Orders	3.47	3.25	1.09	0.69	0.02	2.04	5.44
Depth Location	3.47	3.46	0.13	0.41	0.29	3.28	3.70
Panel H: Euro Night							
Best Depth Orders	11.39	9.08	7.32	1.29	1.49	3.70	26.19
Total Depth Orders	103.12	84.74	64.06	1.30	1.72	31.16	231.78
Best Depth/Best Orders	2.52	2.20	1.28	2.70	16.61	1.26	4.79
Total Depth/Total Orders	4.00	3.73	1.56	1.17	3.10	1.97	7.03
Depth Location	3.42	3.41	0.17	0.01	0.37	3.15	3.71

Table 2.6 (Continued)

Variable	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel I: Yen Day							
Best Depth Orders	18.25	17.42	8.10	0.48	-0.19	6.46	32.81
Total Depth Orders	158.84	153.75	68.58	0.38	-0.23	54.96	280.87
Best Depth/Best Orders	2.02	1.86	0.74	1.56	9.91	1.18	3.29
Total Depth/Total Orders	3.39	3.07	1.27	0.74	0.98	1.80	5.65
Depth Location	3.42	3.41	0.14	0.42	0.44	3.21	3.67
Panel J: Yen Night							
Best Depth Orders	10.39	8.69	6.49	1.26	1.64	3.16	23.43
Total Depth Orders	86.74	73.42	54.51	1.04	0.83	20.92	195.15
Best Depth/Best Orders	2.77	2.38	1.57	2.94	19.27	1.24	5.62
Total Depth/Total Orders	4.35	4.01	1.96	1.23	2.40	1.91	8.02
Depth Location	3.34	3.33	0.20	-0.27	1.40	3.03	3.66
Panel K: Gold Day							
Best Depth Orders	5.73	5.69	1.30	0.35	-0.22	3.83	7.89
Total Depth Orders	50.13	49.71	15.97	0.13	-0.87	25.58	75.81
Best Depth/Best Orders	2.17	2.09	0.54	1.25	3.42	1.46	3.16
Total Depth/Total Orders	2.09	2.02	0.47	1.14	2.81	1.46	2.95
Depth Location	3.28	3.28	0.12	-0.02	0.64	3.08	3.48
Panel L: Gold Night							
Best Depth Orders	3.60	3.45	0.94	1.08	2.66	2.35	5.30
Total Depth Orders	26.36	25.03	8.96	0.67	0.15	14.30	42.47
Best Depth/Best Orders	2.44	2.16	1.21	3.70	30.02	1.28	4.48
Total Depth/Total Orders	2.67	2.47	0.98	2.54	16.81	1.57	4.42
Depth Location	3.30	3.31	0.24	-0.25	1.45	2.91	3.69

Table 2.7 Comparison of Moments

This table presents a comparison of the moments between the contracts. The Panels compare the moments for the best depth and total depth for both the day and the night.

	Mean/Std Dev	Skew	Kurt
Panel A: Best Depth Day			
T-note	1.99	0.35	-0.10
Corn	1.52	7.99	154.20
Oil	3.46	0.83	0.76
Euro	1.94	0.61	-0.24
Yen	1.60	1.05	0.62
Gold	2.74	0.77	0.72
Panel B: Total Depth Day			
T-note	1.96	0.02	-1.04
Corn	2.20	0.98	1.14
Oil	2.41	0.80	0.08
Euro	2.15	0.21	-1.17
Yen	1.63	0.67	-0.84
Gold	2.56	0.30	-0.71
Panel C: Best Depth Night			
T-note	1.35	1.92	9.42
Corn	0.77	6.66	82.35
Oil	1.48	5.41	72.84
Euro	1.58	1.33	3.44
Yen	1.40	1.67	4.06
Gold	1.90	2.30	11.95
Panel D: Total Depth Night			
T-note	1.50	0.93	0.63
Corn	1.28	2.84	11.73
Oil	1.61	2.15	6.65
Euro	1.80	0.73	-0.06
Yen	1.44	0.96	-0.11
Gold	2.03	1.11	1.72

Table 2.8 Symmetry of Depth Levels

This table presents the results for the test of equality of the bid and ask depth for each level during the day and night period.

	Day		Night	
	t statistics	Prob	t statistics	Prob
Panel A: T-note				
Level 1	-0.22	0.83	-0.08	0.93
Level 2	-0.29	0.77	-0.36	0.72
Level 3	-0.35	0.73	-0.27	0.79
Level 4	-0.41	0.68	-0.27	0.79
Level 5	-0.32	0.75	-0.35	0.73
Panel B: Corn				
Level 1	0.10	0.92	2.36	0.02
Level 2	-1.73	0.08	1.74	0.08
Level 3	-2.50	0.01	1.04	0.30
Level 4	-2.97	0.00	0.77	0.44
Level 5	-3.17	0.00	1.07	0.29
Panel C: Oil				
Level 1	-1.78	0.07	-0.93	0.35
Level 2	-1.93	0.05	-0.54	0.59
Level 3	-0.91	0.37	0.08	0.94
Level 4	-0.11	0.92	0.65	0.52
Level 5	0.32	0.75	0.75	0.45
Panel D: Euro				
Level 1	-0.16	0.87	-0.40	0.69
Level 2	0.08	0.94	-0.18	0.85
Level 3	0.05	0.96	0.17	0.87
Level 4	-0.04	0.97	0.10	0.92
Level 5	0.24	0.81	-0.03	0.98
Panel E: Yen				
Level 1	0.02	0.99	0.11	0.91
Level 2	0.10	0.92	0.08	0.93
Level 3	-0.33	0.74	-0.10	0.92
Level 4	-0.28	0.78	-0.18	0.85
Level 5	0.19	0.85	0.00	1.00
Panel F: Gold				
Level 1	-0.14	0.89	0.48	0.63
Level 2	-0.10	0.92	0.48	0.63
Level 3	-0.20	0.84	0.68	0.49
Level 4	-0.28	0.78	0.60	0.55
Level 5	-0.31	0.76	0.57	0.57

Table 2.9 Equality of Depth Levels

This table presents the results for the test of equality of depth across all levels and the test of equality of depth across all levels excluding the best. The results are reported separately for the day and night periods.

	Day		Night	
	F Value	Pr > F	F Value	Pr > F
Panel A: T-note				
Equality All Levels	66.85	<.0001	64.45	<.0001
Equality Excluding Best	1.26	0.2859	4.63	0.0032
Panel B: Corn				
Equality All Levels	115.69	<.0001	51.87	<.0001
Equality Excluding Best	2.93	0.0327	10.51	<.0001
Panel C: Oil				
Equality All Levels	277.04	<.0001	210.70	<.0001
Equality Excluding Best	134.01	<.0001	68.18	<.0001
Panel D: Euro				
Equality All Levels	312.01	<.0001	276.21	<.0001
Equality Excluding Best	61.82	<.0001	53.81	<.0001
Panel E: Yen				
Equality All Levels	159.40	<.0001	130.45	<.0001
Equality Excluding Best	28.83	<.0001	17.17	<.0001
Panel F: Gold				
Equality All Levels	153.66	<.0001	223.52	<.0001
Equality Excluding Best	26.71	<.0001	85.80	<.0001

Table 2.10 Equality of Depth Level Pairs

This table presents the results for the test of equality of depth among pairs of levels for both the day and night. *** represents significance at the five percent level.

	Day		Night	
	Difference	Significance	Difference	Significance
Panel A: T-note				
1 - 2	-989.12	***	-405.55	***
1 - 3	-1088.28	***	-520.73	***
1 - 4	-1024.81	***	-551.80	***
1 - 5	-1035.38	***	-551.17	***
2 - 1	989.12	***	405.55	***
2 - 3	-99.16		-115.18	***
2 - 4	-35.69		-146.25	***
2 - 5	-46.26		-145.63	***
3 - 1	1088.28	***	520.73	***
3 - 2	99.16		115.18	***
3 - 4	63.48		-31.08	
3 - 5	52.90		-30.45	
4 - 1	1024.81	***	551.80	***
4 - 2	35.69		146.25	***
4 - 3	-63.48		31.08	
4 - 5	-10.57		0.63	
5 - 1	1035.38	***	551.17	***
5 - 2	46.26		145.63	***
5 - 3	-52.90		30.45	
5 - 4	10.57		-0.63	
Panel B: Corn				
1 - 2	-53.478	***	-14.561	***
1 - 3	-60.523	***	-20.308	***
1 - 4	-51.531	***	-23.328	***
1 - 5	-52.444	***	-26.629	***
2 - 1	53.478	***	14.561	***
2 - 3	-7.044		-5.747	***
2 - 4	1.948		-8.767	***
2 - 5	1.034		-12.068	***
3 - 1	60.523	***	20.308	***
3 - 2	7.044		5.747	***
3 - 4	8.992	***	-3.020	
3 - 5	8.078		-6.321	***
4 - 1	51.531	***	23.328	***
4 - 2	-1.948		8.767	***
4 - 3	-8.992	***	3.020	
4 - 5	-0.914		-3.301	
5 - 1	52.444	***	26.629	***
5 - 2	-1.034		12.068	***
5 - 3	-8.078		6.321	***
5 - 4	0.914		3.301	

Table 2.10 (Continued)

	Day		Night	
	Difference	Significance	Difference	Significance
Panel C: Oil				
1 - 2	-5.8911	***	-2.3828	***
1 - 3	-11.4449	***	-3.8580	***
1 - 4	-16.2294	***	-4.7588	***
1 - 5	-20.5228	***	-5.5769	***
2 - 1	5.8911	***	2.3828	***
2 - 3	-5.5538	***	-1.4752	***
2 - 4	-10.3383	***	-2.3760	***
2 - 5	-14.6317	***	-3.1941	***
3 - 1	11.4449	***	3.8580	***
3 - 2	5.5538	***	1.4752	***
3 - 4	-4.7845	***	-0.9008	***
3 - 5	-9.0779	***	-1.7189	***
4 - 1	16.2294	***	4.7588	***
4 - 2	10.3383	***	2.3760	***
4 - 3	4.7845	***	0.9008	***
4 - 5	-4.2934	***	-0.8181	***
5 - 1	20.5228	***	5.5769	***
5 - 2	14.6317	***	3.1941	***
5 - 3	9.0779	***	1.7189	***
5 - 4	4.2934	***	0.8181	***
Panel D: Euro				
1 - 2	-69.280	***	-41.783	***
1 - 3	-118.946	***	-71.417	***
1 - 4	-128.272	***	-73.504	***
1 - 5	-113.637	***	-57.360	***
2 - 1	69.280	***	41.783	***
2 - 3	-49.667	***	-29.634	***
2 - 4	-58.992	***	-31.722	***
2 - 5	-44.358	***	-15.577	***
3 - 1	118.946	***	71.417	***
3 - 2	49.667	***	29.634	***
3 - 4	-9.325		-2.087	
3 - 5	5.309		14.058	***
4 - 1	128.272	***	73.504	***
4 - 2	58.992	***	31.722	***
4 - 3	9.325		2.087	
4 - 5	14.634	***	16.145	***
5 - 1	113.637	***	57.360	***
5 - 2	44.358	***	15.577	***
5 - 3	-5.309		-14.058	***
5 - 4	-14.634	***	-16.145	***

Table 2.10 (Continued)

	Day		Night	
	Difference	Significance	Difference	Significance
Panel E: Yen				
1 - 2	-63.057	***	-43.340	***
1 - 3	-107.342	***	-66.100	***
1 - 4	-106.071	***	-60.666	***
1 - 5	-85.329	***	-48.886	***
2 - 1	63.057	***	43.340	***
2 - 3	-44.285	***	-22.760	***
2 - 4	-43.014	***	-17.326	***
2 - 5	-22.272	***	-5.546	
3 - 1	107.342	***	66.100	***
3 - 2	44.285	***	22.760	***
3 - 4	1.271		5.434	
3 - 5	22.013	***	17.214	***
4 - 1	106.071	***	60.666	***
4 - 2	43.014	***	17.326	***
4 - 3	-1.271		-5.434	
4 - 5	20.742	***	11.780	***
5 - 1	85.329	***	48.886	***
5 - 2	22.272	***	5.546	
5 - 3	-22.013	***	-17.214	***
5 - 4	-20.742	***	-11.780	***
Panel F: Gold				
1 - 2	-7.6008	***	-3.5517	***
1 - 3	-10.6933	***	-6.3120	***
1 - 4	-11.9680	***	-8.3170	***
1 - 5	-13.2133	***	-9.4924	***
2 - 1	7.6008	***	3.5517	***
2 - 3	-3.0925	***	-2.7603	***
2 - 4	-4.3671	***	-4.7653	***
2 - 5	-5.6124	***	-5.9406	***
3 - 1	10.6933	***	6.3120	***
3 - 2	3.0925	***	2.7603	***
3 - 4	-1.2746		-2.0050	***
3 - 5	-2.5199	***	-3.1804	***
4 - 1	11.9680	***	8.3170	***
4 - 2	4.3671	***	4.7653	***
4 - 3	1.2746		2.0050	***
4 - 5	-1.2453		-1.1754	***
5 - 1	13.2133	***	9.4924	***
5 - 2	5.6124	***	5.9406	***
5 - 3	2.5199	***	3.1804	***
5 - 4	1.2453		1.1754	***

Table 2.11 Depth Comparison between Day and Night

This table presents results for the comparison of depth between the day and night periods. Best depth in Panel A is defined as the sum of depth at the first level on both sides of the limit order book. Total depth in Panel B is defined as the sum of depth across all five levels on both sides of the limit order book.

	t statistic	Prob
Panel A: Best Depth		
T-note	-16.81	<.0001
Corn	-22.99	<.0001
Oil	-22.89	<.0001
Euro	-13.79	<.0001
Yen	-8.27	<.0001
Gold	-16.32	<.0001
Panel B: Total Depth		
T-note	-14.14	<.0001
Corn	-29.01	<.0001
Oil	-23.53	<.0001
Euro	-16.14	<.0001
Yen	-10.16	<.0001
Gold	-14.76	<.0001

Figure 2.1 Depth Message Updates

This figure presents the percentage of depth updates for best depth and other depth for each futures contract. Best depth refers to message updates where the best level is updated. Other depth represents the depth message updates where the best level is not updated.

Figure 2.2 Distribution of T-note Futures Best Depth (Top) and Total Depth (Bottom)

This figure presents the distribution of the best depth for day and night in the top panel and the distribution of the total depth for day and night in the bottom panel. The distribution is generated using five-minute intervals.

Figure 2.3 Distribution of Corn Futures Best Depth (Top) and Total Depth (Bottom)

This figure presents the distribution of the best depth for day and night in the top panel and the distribution of the total depth for day and night in the bottom panel. The distribution is generated using five-minute intervals.

Figure 2.4 Distribution of Oil Futures Best Depth (Top) and Total Depth (Bottom)

This figure presents the distribution of the best depth for day and night in the top panel and the distribution of the total depth for day and night in the bottom panel. The distribution is generated using five-minute intervals.

Figure 2.5 Distribution of Euro Futures Best Depth (Top) and Total Depth (Bottom)

This figure presents the distribution of the best depth for day and night in the top panel and the distribution of the total depth for day and night in the bottom panel. The distribution is generated using five-minute intervals.

Figure 2.6 Distribution of Yen Futures Best Depth (Top) and Total Depth (Bottom)

This figure presents the distribution of the best depth for day and night in the top panel and the distribution of the total depth for day and night in the bottom panel. The distribution is generated using five-minute intervals.

Figure 2.7 Distribution of Gold Futures Best Depth (Top) and Total Depth (Bottom)

This figure presents the distribution of the best depth for day and night in the top panel and the distribution of the total depth for day and night in the bottom panel. The distribution is generated using five-minute intervals.

Figure 2.8 T-note Futures Depth

This figure presents the intraday behavior of the depth at each level. Each sequential depth level includes the depth at the previous levels.

Figure 2.9 Corn Futures Depth

This figure presents the intraday behavior of the depth at each level. Each sequential depth level includes the depth at the previous levels.

Figure 2.10 Oil Futures Depth

This figure presents the intraday behavior of the depth at each level. Each sequential depth level includes the depth at the previous levels.

Figure 2.11 Euro Futures Depth

This figure presents the intraday behavior of the depth at each level. Each sequential depth level includes the depth at the previous levels.

Figure 2.12 Yen Futures Depth

This figure presents the intraday behavior of the depth at each level. Each sequential depth level includes the depth at the previous levels.

Figure 2.13 Gold Futures Depth

This figure presents the intraday behavior of the depth at each level. Each sequential depth level includes the depth at the previous levels.

Figure 2.14 Limit Order Book for T-note Futures

This figure presents the shape of the limit order book for all five levels on the bid and ask side.

Figure 2.15 Limit Order Book for Corn Futures

This figure presents the shape of the limit order book for all five levels on the bid and ask side.

Figure 2.16 Limit Order Book for Oil Futures

This figure presents the shape of the limit order book for all five levels on the bid and ask side.

Figure 2.17 Limit Order Book for Euro Futures

This figure presents the shape of the limit order book for all five levels on the bid and ask side.

Figure 2.18 Limit Order Book for Yen Futures

This figure presents the shape of the limit order book for all five levels on the bid and ask side.

Figure 2.19 Limit Order Book for Gold Futures

This figure presents the shape of the limit order book for all five levels on the bid and ask side.

CHAPTER 3: THE RELATION BETWEEN DEPTH AND SPREAD

3.1. Introduction

Finance literature shows that liquidity includes both a quantity dimension (depth) and a cost dimension (spread). In particular, Harris (1990) defines liquidity as the willingness of some traders to take the opposite side of a trade at a low cost. In other words, in a liquid market many traders are willing to transact (provide a large depth) at a low cost (a small spread). Market participants can adjust to changing market conditions by modifying either the quantity and/or the cost dimensions. For example, if there is an indication that the probability of informed trading in a market has increased, then market participants can react by either adjusting the spread or the quantity available. In addition, Lee, Mucklow, and Ready (1993) argue that inferences about liquidity shifts cannot be made on the basis of depth or spread alone, but instead must be considered contemporaneously.

Although the interaction between depth and spread is a topic considered in prior research, the focus of most of these studies is the depth and spread at the best bid-ask level. For example, Vo (2007) employs the best depth and spread and finds an inverse intraday relation between the first level of depth and the first level of spread, meaning that traders actively manage both the price and quantity dimensions of liquidity at the best bid-ask level.

On the other hand, very little research focuses on the interaction between depth and spread beyond the first level, especially for U.S. futures markets. In this chapter, the relation between the depth and spread, as well as their individual intraday behavior, is examined for the electronic U.S. futures markets in the context of the five deep limit

order book. In addition, I look beyond the historical approach of only examining the traditional (open outcry) trading hours and investigate the interaction between the quantity and cost dimensions of liquidity for both the open outcry (day) and the night (non-open outcry) electronic market.

3.2. Literature Review

The temporal variations of depth and spread, as well as their interactions, are examined in past research. However, most of these studies only employ depth at the best bid-ask spread level. The use of depth at only the best level is due to the lack of available data at deeper levels. Lee, Mucklow, and Ready (1993) examine the intraday shape of depth and spread for New York Stock Exchange stocks, finding a narrow depth at both the opening and closing of trading relative to the middle of the day, i.e. an inverted U-shaped pattern. Such a pattern is opposite the pattern for the bid-ask spread, which possess wide spreads at both the open and close of the trading day. However, Lee, Mucklow, and Ready do not employ control variables or test for the statistical significance of the depth and spread patterns.

Brockman and Chung (1999) investigate the temporal behavior of stock depth traded on the Stock Exchange of Hong Kong (SEHK), determining that an inverted U-shaped depth pattern exists. Although they employ control variables for known systematic factors that affect depth, their measure of depth does not use depth beyond the first level. In addition, Vo (2007) examines the relation between depth and spread and their respective intraday patterns for Toronto Stock Exchange stocks. He finds a U-shaped intraday bid-ask spread pattern and an intraday depth pattern that is increasing

over the day with a narrow depth at the market open and a wide depth at the market close. Moreover, the presented relation between the depth and spread is negative.

The intraday behavior of depth and spread for three interest rate futures contracts on the Sydney Futures Exchange (SFE) is explored by Frino, Lepone, and Wearin (2008). A declining intraday depth pattern, characterized by large depth at the open and small depth at the close is documented at the best depth level. In addition, the spread pattern is opposite the depth pattern, with large spreads at the open and small spreads at the close. This article does explicitly model the relation between the depth and spread, but does not consider depth beyond the first level.

Contrary to the prior listed literature, Ahn and Cheung (1999) examine the intraday temporal behavior of five-deep depth and the best spreads. They employ two measures of depth, namely the dollar depth at the best bid-ask level and the cumulative dollar depth at the five levels on both sides of the book, using stocks on the Stock Exchange of Hong Kong (SEHK). They find a U-shaped intraday pattern for the best spreads and a reverse U-shape intraday pattern for dollar depth and cumulative dollar depth. Results of a correlation analysis between the depth and spread provide evidence in support of a negative association between the spread and depth. However, they do not specify whether this negative relation is for the best depth or the cumulative depth values. In addition, control variables are not included in the regressions for the statistical significance of the intraday patterns.

Overall, the intraday depth pattern results are not consistent across studies. Lee, Mucklow, and Ready (1993), Brockman and Chung (1999), and Ahn and Cheung (1999) document an inverse U-shaped intraday depth pattern for stocks. Meanwhile, Vo (2007)

and Frino, Lepone, and Wearin (2008) find an increasing depth pattern for stocks and a decreasing depth pattern for futures, respectively. However, the inverse relation between the depth and spread is consistent across studies.

This study differs from the previous literature in several ways. Most importantly, the entire five-deep limit order book is utilized to examine the relation between depth and spread in this study, as opposed to the best depth and spread in other studies. Secondly, both the day and night periods of trading are analyzed here, whereas prior studies concentrate solely on the open outcry (day) session. Finally, I employ electronic U.S. futures contracts, whereas previous research considers stocks and international futures contracts. These extensions fill in a gap in prior literature concerning depth and spread beyond the best level for U.S. futures markets.

3.3. Data

This study employs six futures contracts to examine the depth and spread behavior of these contracts. The futures contracts are the T-note, corn, oil, the euro, yen, and gold futures, and therefore provide a range of contracts over key futures categories. The data for each futures contract is from January 2008 through March, April, or October 2009, depending on the contract. Contracts are rolled over when trading volume in the next out contract exceeds trading in the nearby contract.

Encoded RLC messages are decoded to obtain the limit order book, as described in preceding chapters. However, the entire limit order book data cannot be used for the analysis in this chapter. Although the entire limit order book contains all depth updates,

these updates are not equally distributed in time. Therefore, the depth data is sampled at every second, i.e. the first depth update in each second is taken.¹²

Prior empirical results support a link between the intraday pattern of depth and spread. Since the relation is examined intraday, the day is broken up into specific time intervals. However, no one has determined the “optimal” solution concerning the length of time interval to employ. The time interval should not be too long to preserve the study of an intraday relation. If a very long time interval, such as one hour, is employed then the variation in the underlying variables can become smoothed, making it difficult to ascertain their effects. If the time interval selected is too short, then there may not be enough activity to properly calibrate the underlying variables. As a result two time intervals are employed, specifically five-minute and fifteen-minute intervals. The objective in employing different time intervals is to obtain results independent of the time interval used. In addition, two sets of trading hours are used. The first set of trading hours is termed the “day period” and considers the trading hours during which the open outcry market is open. The second set of trading hours is termed the “night period” and only considers the trading hours outside of the open outcry period. Table 10 lists the electronic and open outcry hours for each futures contract in Central time. The electronic period typically opens at about five p.m. for most of the different contracts and closes at about four p.m. the next day.¹³

¹² For example, there can be thirty depth updates in one second and only one depth update in another second. In order to sample the data at equal intervals, it is sampled every second. Furthermore, the use of the full data set is computationally prohibitive.

¹³ Corn is the only futures contract with a trading halt, which occurs between 6:00 a.m. and 9:30 a.m. Central time. The open outcry hours vary for each contract.

3.4. Methodology

The first goal of this chapter is to examine the intraday behavior of the depth and spread. The second objective of this chapter is to establish the relation between the depth and spread.

3.4.1. Behavior of Depth and Spread

Since the data consists of the limit order book, the measures of depth and spread need to account for the five levels of depth. The total depth in the five-deep limit order book is calculated as the sum of the volume available over all five levels of depth:

$$Total\ Depth = \sum_{i=1}^5 (Depth_{Bid\ i} + Depth_{Ask\ i}) \quad (3.1)$$

The traditional spread measure is extended to account for all five levels of the limit order book. The bid-ask spread at the best level is traditionally defined as follows:

$$Spread = Price_{Ask} - Price_{Bid} \quad (3.2)$$

This measure is extended to all levels by calculating the sum of the depth-weighted spread over all levels as follows:

$$Total\ Spread = \sum_{i=1}^5 \left[\left(\frac{Depth_i}{Total\ Depth} \right) (Price_{Ask\ i} - Price_{Bid\ i}) \right] \quad (3.3)$$

$$\text{where } Depth_i = Depth_{Bid\ i} + Depth_{Ask\ i} \quad (3.4)$$

$$\text{and } Total\ Depth = \sum_{i=1}^5 (Depth_{Bid\ i} + Depth_{Ask\ i}) \quad (3.5)$$

Based on the overwhelming conclusion of prior literature that the best depth and spread is not constant within the day, the following research hypotheses are proposed:¹⁴

¹⁴ For ease of exposition, the total depth henceforth is referred to as “depth,” and the total spread will be referred to as the “spread.”

Research hypothesis 1: There is a variation in the intraday pattern of the depth.

Research hypothesis 2: There is a variation in the intraday pattern of the spread.

In order to formally test these two research hypotheses, the following four regressions are estimated separately for each futures contract:

$$Depth_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t \quad (3.6)$$

$$Depth_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t \quad (3.7)$$

$$Spread_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t \quad (3.8)$$

$$Spread_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t \quad (3.9)$$

The D_i variables represent dummy variables that take a value of one for the first half hour and last half hour of the trading day and zero otherwise; t refers to the time intervals during the day. Equations 3.6 and 3.8 are estimated using five-minute interval data and therefore contain six dummy variables at the opening and closing of the trading day. Equations 3.7 and 3.9 are estimated using fifteen-minute interval data and therefore contain two time dummy variables at the opening and closing of the trading day. The T variable represents the last time interval of the day and varies with each futures since each contract remains open for a different length of time. The trading day also takes two different specifications, which include the day and night trading hours, as previously described in the data section.

A time interval under consideration is compared with the average of the omitted (middle of the day) intervals. The middle of the day dummies take a value of zero in order to avoid perfect multicollinearity among the variables. Therefore, a significantly

positive (negative) coefficient on the time dummy variable reflects higher (lower) values for the interval under consideration relative to the middle of the day. These regressions, and all ensuing regressions, are estimated using Hansen's (1982) generalized method of moments (GMM) procedure. In addition, the Newey and West (1987) correction is applied to assure robustness relative to autocorrelation and heteroskedasticity.

3.4.2. Relation between Depth and Spread

The second goal of this chapter is to ascertain the relation between the depth and spread. The relation between total depth and total spread has not been examined in prior research. However, based on the empirical results of Vo (2007) who uses the best depth and spread data, the following research hypothesis is examined:

Research hypothesis 3: An inverse relation exists between the total depth and the total spread.

Therefore, in order to investigate the relation between depth and spread, the following regressions are estimated for each futures contract:

$$Depth_t = \alpha_0 + \beta_0 Spread + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t \quad (3.10)$$

$$Depth_t = \alpha_0 + \beta_0 Spread + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t + \varepsilon_i \quad (3.11)$$

A statistically significant negative coefficient on spread would verify an inverse relation between depth and spread, after controlling for the intraday variation.

Aitken and Frino (1996) and Ding (1999) identify three factors that are shown to affect spreads, namely trade activity, price volatility, and price level. If the depth and spread are truly systematically related, then such a relation should exist after removing

these other factors.¹⁵ Moreover, Harris (1994) also identifies volatility and volume as key variables aiding in the explanation of changes in the depth level. Therefore, I estimate the following two models:

$$\begin{aligned} Depth_t = & \alpha_0 + \gamma_1 Spread + \gamma_2 Volume_t + \gamma_3 Level_t + \gamma_4 Volatility_t \\ & + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t \end{aligned} \quad (3.12)$$

$$\begin{aligned} Depth_t = & \alpha_0 + \gamma_1 Spread + \gamma_2 Volume_t + \gamma_3 Level_t + \gamma_4 Volatility_t \\ & + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t \end{aligned} \quad (3.13)$$

where the volume is calculated as the trade volume in each time interval, the price level is represented by the mean trade price in each time interval, and the volatility is measured by the standard deviation of the trade prices in each time interval. Furthermore, I investigate the depth-spread relation during the day and night session separately.

3.5. Results

The first part of the results describes the summary statistics of the data. The next portion of the results discusses the intraday behavior of the depth and spread. The subsequent section describes the results for the depth-spread relation.

3.5.1. Summary Statistics

Table 3.2 reports the summary statistics for the spread, volume, frequency, level, and volatility for the day trading hours using the five-minute intervals and Table 3.3 shows the summary of the fifteen-minute intervals during the day. The spread, level, and volatility are similar for the five-minute and fifteen-minute intervals for the individual

¹⁵ Of course, if these control variables are proxies for depth (are highly interrelated) then no relation may exist on a statistical basis after these factors are removed.

futures contracts. However, the volume and frequency is obviously different between the two time intervals.¹⁶

Table 3.4 summarizes the spread, volume, frequency, level, and volatility for the equivalent night trading period with five-minute intervals, whereas Table 3.5 shows the summary for the fifteen-minute intervals. The spread, level, and volatility are comparable for both the five-minute and fifteen-minute intervals during the night session. Comparing the summary statistics for the day (Tables 3.2 and 3.3) and night (Table 3.4 and 3.5) periods, I find that the spread is smaller and volume is larger for the day period for each futures contract relative to the night time interval. For example, Panel B of Table 3.3 (day period) shows corn has a spread of 1.39, whereas in Panel B of Table 3.4 (night period) corn possesses a spread of 1.89.

Figures 3.1 through 3.6 depict the distribution of the best spread and total spread for the T-note, corn, oil, euro, yen, and gold futures during the day and night sessions. These figures illustrate that both the best and total spread are more dispersed during the night relative to the day. Furthermore, the distribution of the best spread is more skewed to the right compared to the total spread.

The intraday patterns of the depth and spread are pictured in Figures 3.7 through 3.12 for the T-note, corn, oil, euro, yen, and gold futures over the entire day. The figures support a reverse U-shaped pattern for the depth. In addition, the intraday pattern of the spread for these contracts is U-shaped.

¹⁶ For example, oil has an average volume of 8405.23 during the five-minute time intervals in Panel A Table 3.2 and a volume of 24904.39 during the fifteen-minute intervals in Panel A Table 3.3.

3.5.2. Intraday Patterns

The regression results for the intraday patterns of the depth and spread are presented in Tables 3.6 through 3.11 for each futures contract. In each table, Panels A and B provide results for the intraday variation in the depth and Panels B and C for the intraday variation in the spread.

Table 3.6 provides results for the T-note futures contract. Panel A shows evidence of an inverse U-shaped pattern in the depth for both the day and night hours using five minute intervals, as shown by the negative and significant dummy variables at the beginning and end of each period. Panel B supports a similar pattern for the depth of T-note futures using fifteen-minute intervals during the day. Panel C shows an increasing bid-ask spread pattern for the day with negative and significant time dummies at the open and positive and significant time dummies at the close. In Panel D, using fifteen-minute intervals, the shape of the spread during the day period fits a similar increasing pattern. However for the night period, the intraday spread exhibits a declining pattern which is characterized by a large spread at the open and a declining spread at the close. In general, the depth results exhibit an inverse U-shaped pattern for the day and night across the futures contracts. Overall, the spread results (increasing pattern) for the day session for both the five-minute and fifteen-minute intervals are consistent across all six futures contracts. However, the spread results for the night vary.

3.5.3. Relation between Depth and Spread

The next set of tables show the results for the relation between depth and spread. In Table 3.13 (corn), the negative and statistically significant coefficient on the spread for the five and fifteen minute interval support an inverse relation between depth and spread.

Moreover, this result holds for both the day and night sessions. The inverse relation between depth and spread is also documented in Tables 3.14, 3.15, 3.16, and 3.17 for the day and night sessions and for different time intervals. After controlling for the intraday variation and determinants of depth (including volume, level, and volatility), the results still hold. The only futures contract for which this inverse relation does not hold is the T-note futures, which shows a positive relation between the depth and spread.

3.6. Conclusion

A few interesting points can be discussed here. The choice of the time interval used in the intraday analysis of the depth and spread is important and can influence the subsequent results. For example, consider a contract where the depth is narrow for the first three minutes of the day and then quickly reverses to the mean. If five-minute intervals are employed then this variation will be captured. However, if fifteen minute intervals are employed then this variation may not be captured, because the variation would be averaged out with the other twelve minutes in the time interval. The behavior of the spread for the yen futures exemplifies such a scenario. The intraday pattern of the spread is different between the day and night sessions; this was not previously observed due to the lack of night session studies on the spread. However, the inverse relation between the depth and spread hold for both the day and night sessions.

In conclusion, this chapter provides results for the behavior of the total depth and spread, as well as their interaction, for six U.S. futures markets. The intraday behavior of the depth and spread is generally found to have a systemic pattern. Strong evidence to support an inverse relation between the depth and spread also exists, even after controlling for known explanatory factors.

The results mirror the general findings of Lee, Mucklow, and Ready (1993) for equities, that narrow depths are associated with large spreads. This association implies that limit order traders actively manage both price (spread) and quantity (depth) dimensions of liquidity. However, their conclusion only holds for the best level. The results of this chapter, using five deep depth data extend their implication beyond stocks and beyond the best depth for futures markets, i.e. limit order traders actively manage spreads and depth along the five deep limit order book.

Table 3.1 Open Outcry and Non-Open Outcry Trading Hours

This table lists the open outcry and non-open outcry trading hours in Central time for each futures contract. The open outcry period represents day trading and the non-open outcry period represents night trading.

Futures Contract	Open Outcry (Day)	Non-Open Outcry(Night)
T-note	07:20 - 14:00	17:30 - 07:19 and 14:01 - 16:00
Corn	09:30 - 13:15	18:00 - 06:00
Oil	08:00 - 13:30	17:00 - 07:59 and 13:31 - 16:15
Euro	07:20 - 14:00	17:00 - 07:19 and 14:01 - 16:00
Yen	07:20 - 14:00	17:00 - 07:19 and 14:01 - 16:00
Gold	07:20 - 12:30	17:00 - 07:19 and 12:31 - 16:15

Table 3.2 Summary Five-Minute Day

This table presents the summary statistics for the five-minute time intervals during the day for each futures contract. Spread is calculated as the sum of the depth-weighted spreads across all five levels. Volume is computed as the sum of trade volume in each time interval. Level is represented by the mean trade price in each time interval. Volatility is defined by the standard deviation of trade prices in each time interval.

	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel A: T-note							
Spread	0.09	0.09	0.00	-0.27	0.66	0.08	0.09
Volume	8405.23	6784.00	6323.49	2.59	12.10	2142.50	19791.50
Frequency	507.65	427.00	333.35	2.58	13.07	161.00	1101.50
Level	115.96	115.71	2.20	0.47	0.32	112.41	120.34
Volatility	0.02	0.02	0.01	3.20	19.82	0.01	0.05
Panel B: Corn							
Spread	1.39	1.38	0.11	0.85	9.20	1.21	1.56
Volume	1526.00	1031.50	1589.69	3.15	15.05	240.00	4518.00
Frequency	551.58	380.00	564.03	3.01	13.40	86.00	1622.00
Level	512.72	533.24	117.19	0.23	-0.77	351.97	747.00
Volatility	0.52	0.42	0.41	2.87	15.18	0.15	1.27
Panel C: Oil							
Spread	7.40	7.25	0.72	2.79	22.07	6.58	8.63
Volume	6831.45	4465.00	7654.13	3.81	19.10	1751.00	20915.00
Frequency	3686.22	2657.50	3293.53	3.01	12.27	1075.00	10712.00
Level	87.46	95.02	33.90	-0.12	-1.42	39.51	136.59
Volatility	0.11	0.08	0.10	3.93	22.60	0.04	0.26
Panel D: Euro							
Spread	6.19	6.11	0.37	0.92	0.78	5.71	6.93
Volume	3079.93	2271.00	2849.02	3.27	19.98	578.00	8154.00
Frequency	1499.91	1060.00	1459.68	3.30	21.69	252.00	4256.00
Level	14.19	14.18	0.99	0.05	-1.12	12.67	15.72
Volatility	0.00	0.00	0.01	8.40	93.90	0.00	0.01

Table 3.2 (Continued)

	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel E: Yen							
Spread	6.21	6.11	0.47	1.24	2.55	5.63	7.09
Volume	1552.78	1142.00	1453.10	3.24	23.20	248.00	4214.00
Frequency	711.25	540.00	634.70	3.64	29.38	146.00	1836.00
Level	0.01	0.01	0.00	0.04	-1.13	0.01	0.01
Volatility	0.00	0.00	0.00	4.79	32.50	0.00	0.00
Panel F: Gold							
Spread	6.36	6.26	0.53	1.45	4.64	5.70	7.34
Volume	2399.59	1866.00	2014.07	3.11	16.93	552.00	5969.00
Frequency	1171.02	952.00	866.43	2.78	13.36	329.00	2725.00
Level	88.21	89.25	6.28	-0.72	0.12	74.73	97.16
Volatility	0.06	0.05	0.08	8.17	86.97	0.02	0.13

Table 3.3 Summary Fifteen-Minute Day

This table presents the summary statistics for the fifteen-minute time intervals during the day for each futures contract. Spread is calculated as the sum of the depth-weighted spreads across all five levels. Volume is computed as the sum of trade volume in each time interval. Level is represented by the mean trade price in each time interval. Volatility is defined by the standard deviation of trade prices in each time interval.

	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel A: T-note							
Spread	0.09	0.09	0.00	-0.13	0.76	0.08	0.09
Volume	24904.39	20837.00	15919.33	1.68	4.03	7611.00	55396.00
Frequency	1504.14	1302.00	842.60	1.68	4.81	545.00	3111.00
Level	115.96	115.71	2.20	0.47	0.33	112.41	120.33
Volatility	0.04	0.03	0.03	2.86	15.36	0.01	0.08
Panel B: Corn							
Spread	1.39	1.39	0.09	1.31	16.14	1.26	1.52
Volume	4567.64	3300.00	4008.89	2.24	6.69	913.00	13040.00
Frequency	1650.99	1193.00	1472.25	2.26	6.82	296.00	4781.00
Level	513.04	533.35	117.43	0.23	-0.78	351.97	747.00
Volatility	0.90	0.73	0.66	2.12	7.30	0.24	2.12
Panel C: Oil							
Spread	7.40	7.26	0.68	2.68	20.33	6.63	8.58
Volume	17894.34	13882.00	13067.82	2.52	9.08	6265.00	45489.00
Frequency	10038.04	8151.00	6336.32	2.03	6.05	3755.00	22842.00
Level	87.45	95.04	33.90	-0.12	-1.42	39.49	136.62
Volatility	0.18	0.15	0.13	3.40	18.50	0.06	0.40
Panel D: Euro							
Spread	6.19	6.11	0.36	0.96	0.77	5.74	6.91
Volume	9123.99	7163.00	7328.55	2.51	11.59	2084.00	22682.00
Frequency	4443.33	3310.00	3904.72	2.66	13.43	846.00	12026.00
Level	14.19	14.18	0.99	0.05	-1.12	12.67	15.72
Volatility	0.01	0.01	0.01	6.81	70.01	0.00	0.02

Table 3.3 (Continued)

	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel E: Yen							
Spread	6.20	6.10	0.45	1.23	2.20	5.65	7.07
Volume	4599.84	3546.00	3718.58	2.32	10.00	968.00	11722.00
Frequency	2106.94	1662.00	1642.70	2.94	20.61	526.00	5084.00
Level	0.01	0.01	0.00	0.04	-1.13	0.01	0.01
Volatility	0.00	0.00	0.00	3.44	21.29	0.00	0.00
Panel F: Gold							
Spread	6.36	6.25	0.49	1.52	4.23	5.78	7.29
Volume	7084.21	5789.00	5076.28	2.58	12.15	1981.00	16399.00
Frequency	3457.14	2926.00	2229.42	2.28	9.71	1104.00	7622.00
Level	88.21	89.25	6.28	-0.72	0.12	74.72	97.15
Volatility	0.10	0.08	0.09	5.44	44.69	0.03	0.22

Table 3.4 Summary Five-Minute Night

This table presents the summary statistics for the five-minute time intervals during the night for each futures contract. Spread is calculated as the sum of the depth-weighted spreads across all five levels. Volume is computed as the sum of trade volume in each time interval. Level is represented by the mean trade price in each time interval. Volatility is defined by the standard deviation of trade prices in each time interval.

	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel A: T-note							
Spread	0.09	0.09	0.01	-0.14	0.04	0.08	0.10
Volume	1099.65	523.00	1713.73	5.22	56.50	17.00	4075.00
Frequency	73.40	39.00	102.71	4.21	32.70	4.00	262.00
Level	115.95	115.76	2.18	0.39	0.28	112.28	120.12
Volatility	0.01	0.01	0.01	6.66	79.04	0.00	0.03
Panel B: Corn							
Spread	1.89	1.82	0.44	0.44	-0.36	1.25	2.73
Volume	44.78	12.00	139.92	13.09	275.99	1.00	168.00
Frequency	18.04	7.00	45.32	11.40	211.14	1.00	64.00
Level	514.18	532.54	117.73	0.25	-0.73	352.25	746.71
Volatility	0.20	0.16	0.19	2.83	22.20	0.00	0.54
Panel C: Oil							
Spread	9.77	9.19	2.50	0.90	0.31	6.73	14.79
Volume	454.52	116.00	1109.22	6.75	82.54	6.00	1969.00
Frequency	275.17	71.00	653.70	7.02	103.54	6.00	1206.00
Level	87.42	95.14	34.01	-0.11	-1.43	39.81	136.72
Volatility	0.04	0.03	0.08	9.87	135.78	0.01	0.11
Panel D: Euro							
Spread	6.35	6.22	0.57	0.91	0.48	5.64	7.50
Volume	760.17	414.00	1002.11	4.03	34.46	38.00	2566.00
Frequency	375.52	208.00	490.99	4.79	60.29	24.00	1236.00
Level	14.19	14.17	0.99	0.05	-1.10	12.66	15.73
Volatility	0.00	0.00	0.01	12.06	178.60	0.00	0.01

Table 3.4 (Continued)

	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel E: Yen							
Spread	6.37	6.15	0.77	1.46	2.34	5.53	7.96
Volume	416.73	254.00	520.65	4.24	37.31	22.00	1330.00
Frequency	199.24	128.00	232.08	3.83	31.55	14.00	608.00
Level	0.01	0.01	0.00	0.04	-1.13	0.01	0.01
Volatility	0.00	0.00	0.00	8.41	99.15	0.00	0.00
Panel F: Gold							
Spread	7.78	7.39	1.56	1.23	1.50	5.96	11.04
Volume	356.90	180.00	608.69	7.77	126.54	18.00	1213.00
Frequency	174.21	100.00	264.01	7.25	114.84	12.00	552.00
Level	88.20	89.24	6.30	-0.72	0.12	74.61	97.30
Volatility	0.03	0.02	0.07	10.13	122.61	0.01	0.08

Table 3.5 Summary Fifteen-Minute Night

This table presents the summary statistics for the fifteen-minute time intervals during the night for each futures contract. Spread is calculated as the sum of the depth-weighted spreads across all five levels. Volume is computed as the sum of trade volume in each time interval. Level is represented by the mean trade price in each time interval. Volatility is defined by the standard deviation of trade prices in each time interval.

	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel A: T-note							
Spread	0.09	0.09	0.01	-0.12	0.17	0.08	0.10
Volume	3217.96	1728.00	4461.57	4.19	36.53	137.00	11457.00
Frequency	214.91	123.00	276.98	3.64	23.98	17.00	743.00
Level	115.95	115.76	2.18	0.39	0.28	112.29	120.13
Volatility	0.02	0.01	0.02	3.73	24.61	0.01	0.05
Panel B: Corn							
Spread	1.90	1.84	0.41	0.46	-0.30	1.32	2.69
Volume	128.44	43.00	329.54	8.84	117.11	3.00	481.00
Frequency	51.47	22.00	111.74	8.07	97.72	3.00	183.00
Level	513.74	532.30	117.76	0.25	-0.73	352.25	746.61
Volatility	0.33	0.27	0.28	3.12	18.58	0.05	0.82
Panel C: Oil							
Spread	9.79	9.28	2.31	0.84	0.14	6.93	14.31
Volume	1400.67	395.00	3158.44	5.69	50.68	38.00	6444.00
Frequency	847.54	215.00	1889.18	5.76	53.87	27.00	3725.00
Level	87.48	95.20	33.99	-0.11	-1.43	39.80	136.73
Volatility	0.07	0.05	0.09	6.63	69.41	0.02	0.19
Panel D: Euro							
Spread	6.36	6.22	0.54	0.84	0.14	5.68	7.42
Volume	2329.99	1362.00	2710.01	3.23	21.43	192.00	7396.00
Frequency	1150.86	664.00	1340.61	3.49	27.80	102.00	3604.00
Level	14.19	14.17	0.99	0.05	-1.10	12.66	15.73
Volatility	0.01	0.00	0.01	11.16	159.24	0.00	0.01

Table 3.5 (Continued)

	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel E: Yen							
Spread	6.37	6.16	0.73	1.35	1.81	5.57	7.90
Volume	1279.01	874.00	1376.87	3.53	25.54	120.00	3774.00
Frequency	611.50	430.00	621.23	2.86	16.02	58.00	1754.00
Level	0.01	0.01	0.00	0.04	-1.13	0.01	0.01
Volatility	0.00	0.00	0.00	6.11	56.80	0.00	0.00
Panel F: Gold							
Spread	7.82	7.43	1.44	1.21	1.31	6.17	10.78
Volume	1006.18	606.00	1322.12	6.69	121.98	86.00	3141.00
Frequency	494.74	322.00	593.20	6.36	111.74	54.00	1455.00
Level	88.21	89.24	6.30	-0.72	0.12	74.61	97.30
Volatility	0.05	0.04	0.08	8.09	84.54	0.01	0.13

Table 3.6 T-note Intraday Patterns of Depth and Spread

This table presents the coefficient estimates for the following models:

$$\text{Model 1: } \text{Depth}_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 2: } \text{Depth}_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

$$\text{Model 3: } \text{Spread}_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 4: } \text{Spread}_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

Depth is calculated as the sum of the depth available across all five levels. Spread is calculated as the sum of the depth-weighted spreads across all five levels. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. Models 1 and 3 employ data based on five-minute intervals. Models 2 and 4 employ data based on fifteen-minute intervals. Each regression is estimated separately for the day and night period. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

	Day	Night
Panel A: Model 1		
Intercept	8270.87 (100.11*)	3979.69 (122.98*)
D ₁	-1478.5 (-5.58*)	-2594.2 (-31.07*)
D ₂	-2491.4 (-9.69*)	-2299.1 (-21.38*)
D ₃	-1255.6 (-4.82*)	-2177.8 (-18.91*)
D ₄	-117.23 (-0.40)	-2116.6 (-17.62*)
D ₅	188.694 (0.64)	-2096.2 (-17.29*)
D ₆	218.334 (0.76)	-2027.3 (-17.36*)
D _{T-5}	-908.70 (-3.35*)	663.697 (3.48*)
D _{T-4}	-883.25 (-3.20*)	609.180 (3.19*)
D _{T-3}	-849.36 (-3.11*)	382.015 (2.15**)
D _{T-2}	-901.78 (-3.28*)	230.789 (1.32)
D _{T-1}	-956.83 (-3.47*)	-24.754 (-0.15)
D _T	-726.33 (-2.57**)	-466.71 (-3.07*)
Panel B: Model 2		
Intercept	8280.96 (60.56*)	3949.12 (73.40*)
D ₁	-1724.8 (-6.85*)	-2408.6 (-24.08*)
D ₂	86.682 (0.31)	-2080.0 (-17.39*)
D _{T-1}	-933.92 (-3.51*)	599.465 (3.22*)
D _T	-849.48 (-3.11*)	-87.010 (-0.54)

Table 3.6 (Continued)

Panel C: Model 3		
Intercept	0.086 (1440.47*)	0.089 (1411.30*)
D ₁	-0.003 (-9.27*)	0.000 (0.73)
D ₂	-0.002 (-8.00*)	0.001 (1.03)
D ₃	-0.001 (-3.35*)	0.000 (0.30)
D ₄	-0.001 (-6.62*)	0.001 (1.08)
D ₅	-0.001 (-5.82*)	0.001 (2.25**)
D ₆	-0.001 (-5.38*)	0.002 (2.95*)
D _{T-5}	0.001 (2.85*)	-0.002 (-3.42*)
D _{T-4}	0.001 (2.68*)	-0.002 (-4.16*)
D _{T-3}	0.001 (2.80*)	-0.002 (-5.70*)
D _{T-2}	0.001 (2.11**)	-0.003 (-6.96*)
D _{T-1}	0.000 (1.44)	-0.004 (-7.59*)
D _T	0.000 (-0.36)	-0.005 (-9.93*)
Panel D: Model 4		
Intercept	0.086 (968.53*)	0.089 (1014.68*)
D ₁	-0.002 (-8.97*)	0.001 (1.10)
D ₂	-0.001 (-7.04*)	0.001 (2.38**)
D _{T-1}	0.001 (2.80*)	-0.002 (-5.18*)
D _T	0.000 (0.37)	-0.004 (-9.34*)

Table 3.7 Corn Intraday Patterns of Depth and Spread

This table presents the coefficient estimates for the following models:

$$\text{Model 1: } \text{Depth}_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 2: } \text{Depth}_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

$$\text{Model 3: } \text{Spread}_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 4: } \text{Spread}_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

Depth is calculated as the sum of the depth available across all five levels. Spread is calculated as the sum of the depth-weighted spreads across all five levels. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. Models 1 and 3 employ data based on five-minute intervals. Models 2 and 4 employ data based on fifteen-minute intervals. Each regression is estimated separately for the day and night period. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

	Day	Night
Panel A: Model 1		
Intercept	559.400 (100.69*)	200.386 (103.52*)
D ₁	-79.386 (-6.24*)	73.943 (7.93*)
D ₂	-16.299 (-1.13)	55.648 (6.34*)
D ₃	11.460 (0.79)	59.391 (6.11*)
D ₄	16.797 (1.09)	63.559 (6.16*)
D ₅	12.422 (0.87)	58.133 (5.65*)
D ₆	23.028 (1.49)	56.687 (5.35*)
D _{T-5}	-17.689 (-1.20)	-13.885 (-1.66***)
D _{T-4}	-9.593 (-0.66)	-11.401 (-1.32)
D _{T-3}	-13.426 (-0.86)	-12.237 (-1.42)
D _{T-2}	-12.748 (-0.78)	-7.579 (-0.83)
D _{T-1}	16.829 (0.98)	-1.851 (-0.20)
D _T	46.338 (2.65*)	2.144 (0.23)
Panel B: Model 2		
Intercept	558.594 (68.98*)	198.523 (65.80*)
D ₁	-27.201 (-2.18**)	65.288 (7.68*)
D ₂	16.385 (1.25)	61.362 (6.24*)
D _{T-1}	-13.138 (-0.98)	-14.479 (-1.83***)
D _T	20.669 (1.36)	-2.551 (-0.30)

Table 3.7 (Continued)

Panel C: Model 3		
Intercept	1.385 (732.88*)	1.903 (388.71*)
D ₁	0.027 (4.69*)	-0.343 (-26.69*)
D ₂	-0.004 (-0.66)	-0.376 (-31.05*)
D ₃	-0.010 (-1.69***)	-0.366 (-28.85*)
D ₄	0.000 (0.02)	-0.362 (-26.48*)
D ₅	-0.004 (-0.80)	-0.353 (-26.08*)
D ₆	0.004 (0.69)	-0.355 (-24.42*)
D _{T-5}	0.028 (3.95*)	0.008 (0.31)
D _{T-4}	0.016 (2.21**)	0.013 (0.46)
D _{T-3}	0.018 (2.55**)	-0.002 (-0.06)
D _{T-2}	0.012 (1.56)	0.013 (0.50)
D _{T-1}	-0.002 (-0.22)	0.030 (1.13)
D _T	0.023 (3.11*)	0.014 (0.55)
Panel D: Model 4		
Intercept	1.385 (560.20*)	1.920 (267.19*)
D ₁	0.004 (0.78)	-0.376 (-33.31*)
D ₂	0.000 (-0.11)	-0.368 (-29.13*)
D _{T-1}	0.020 (3.68*)	0.000 (0.00)
D _T	0.015 (2.20**)	0.002 (0.11)

Table 3.8 Oil Intraday Patterns of Depth and Spread

This table presents the coefficient estimates for the following models:

$$\text{Model 1: } \text{Depth}_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 2: } \text{Depth}_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

$$\text{Model 3: } \text{Spread}_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 4: } \text{Spread}_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

Depth is calculated as the sum of the depth available across all five levels. Spread is calculated as the sum of the depth-weighted spreads across all five levels. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. Models 1 and 3 employ data based on five-minute intervals. Models 2 and 4 employ data based on fifteen-minute intervals. Each regression is estimated separately for the day and night period. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

	Day	Night
Panel A: Model 1		
Intercept	102.224 (130.68*)	48.766 (192.28*)
D ₁	-2.273 (-0.94)	-12.089 (-8.10*)
D ₂	0.229 (0.09)	-13.061 (-11.46*)
D ₃	0.040 (0.02)	-11.346 (-9.09*)
D ₄	0.366 (0.15)	-10.923 (-8.54*)
D ₅	1.008 (0.42)	-10.408 (-7.53*)
D ₆	-0.575 (-0.24)	-9.548 (-6.79*)
D _{T-5}	-9.420 (-4.35*)	3.063 (1.95***)
D _{T-4}	-8.468 (-3.97*)	2.966 (1.79***)
D _{T-3}	-8.700 (-3.99*)	1.969 (1.30)
D _{T-2}	-6.279 (-2.69*)	1.153 (0.73)
D _{T-1}	-4.340 (-1.83***)	-1.501 (-1.03)
D _T	14.938 (6.11*)	-1.415 (-0.93)
Panel B: Model 2		
Intercept	102.107 (80.36*)	48.800 (124.88*)
D ₁	-0.624 (-0.27)	-11.615 (-11.65*)
D ₂	0.291 (0.13)	-10.284 (-9.09*)
D _{T-1}	-8.833 (-4.31*)	2.641 (1.87***)
D _T	0.893 (0.41)	-0.251 (-0.18)

Table 3.8 (Continued)

Panel C: Model 3		
Intercept	7.387 (601.80*)	9.679 (471.86*)
D ₁	-0.073 (-1.87***)	4.198 (31.32*)
D ₂	-0.096 (-2.69*)	3.457 (23.57*)
D ₃	-0.064 (-1.82***)	3.250 (20.81*)
D ₄	-0.066 (-1.83***)	3.111 (19.53*)
D ₅	-0.076 (-2.04**)	3.121 (20.60*)
D ₆	-0.046 (-1.26)	2.844 (17.81*)
D _{T-5}	0.261 (4.92*)	0.352 (3.00*)
D _{T-4}	0.234 (4.89*)	0.306 (2.54**)
D _{T-3}	0.271 (5.24*)	0.455 (3.42*)
D _{T-2}	0.252 (4.49*)	0.710 (5.27*)
D _{T-1}	0.219 (3.98*)	0.947 (7.21*)
D _T	-0.011 (-0.24)	1.190 (9.66*)
Panel D: Model 4		
Intercept	7.388 (380.61*)	9.694 (298.67*)
D ₁	-0.078 (-2.24**)	3.504 (30.05*)
D ₂	-0.063 (-1.86***)	3.004 (22.82*)
D _{T-1}	0.255 (5.55*)	0.414 (3.76*)
D _T	0.154 (3.31*)	1.024 (9.24*)

Table 3.9 Euro Intraday Patterns of Depth and Spread

This table presents the coefficient estimates for the following models:

$$\text{Model 1: } \text{Depth}_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 2: } \text{Depth}_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

$$\text{Model 3: } \text{Spread}_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 4: } \text{Spread}_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

Depth is calculated as the sum of the depth available across all five levels. Spread is calculated as the sum of the depth-weighted spreads across all five levels. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. Models 1 and 3 employ data based on five-minute intervals. Models 2 and 4 employ data based on fifteen-minute intervals. Each regression is estimated separately for the day and night period. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

	Day	Night
Panel A: Model 1		
Intercept	649.793 (148.92*)	389.395 (210.67*)
D ₁	2.569 (0.17)	-228.19 (-45.20*)
D ₂	-115.06 (-8.57*)	-189.68 (-28.46*)
D ₃	-97.322 (-7.20*)	-168.91 (-23.98*)
D ₄	-4.210 (-0.29)	-156.94 (-22.26*)
D ₅	16.746 (1.15)	-146.72 (-20.62*)
D ₆	27.275 (1.87***)	-136.28 (-18.83*)
D _{T-5}	-98.516 (-7.06*)	-224.11 (-49.77*)
D _{T-4}	-94.569 (-6.75*)	-226.45 (-50.55*)
D _{T-3}	-93.784 (-6.61*)	-230.71 (-53.06*)
D _{T-2}	-99.630 (-6.99*)	-236.59 (-53.64*)
D _{T-1}	-106.01 (-7.43*)	-237.21 (-58.72*)
D _T	-99.524 (-6.88*)	-247.67 (-59.25*)
Panel B: Model 2		
Intercept	648.640 (90.08*)	387.844 (126.39*)
D ₁	-68.727 (-5.15*)	-192.44 (-30.98*)
D ₂	14.752 (1.04)	-143.63 (-20.07*)
D _{T-1}	-95.244 (-6.93*)	-226.38 (-47.93*)
D _T	-101.56 (-7.23*)	-239.27 (-54.89*)

Table 3.9 (Continued)

Panel C: Model 3		
Intercept	6.195 (1194.92*)	6.331 (1335.56*)
D ₁	-0.151 (-8.67*)	0.298 (9.49*)
D ₂	-0.091 (-4.78*)	0.428 (13.73*)
D ₃	-0.066 (-3.95*)	0.557 (16.73*)
D ₄	-0.121 (-7.42*)	0.538 (17.08*)
D ₅	-0.116 (-7.21*)	0.540 (17.28*)
D ₆	-0.106 (-6.52*)	0.525 (17.22*)
D _{T-5}	0.081 (4.01*)	0.311 (9.80*)
D _{T-4}	0.068 (3.34*)	0.363 (10.59*)
D _{T-3}	0.057 (2.85*)	0.356 (10.40*)
D _{T-2}	0.035 (1.85***)	0.396 (12.62*)
D _{T-1}	0.028 (1.45)	0.346 (10.50*)
D _T	-0.005 (-0.26)	0.342 (10.94*)
Panel D: Model 4		
Intercept	6.196 (735.15*)	6.331 (813.07*)
D ₁	-0.103 (-6.25*)	0.433 (15.98*)
D ₂	-0.116 (-7.35*)	0.521 (19.90*)
D _{T-1}	0.053 (2.91*)	0.346 (12.19*)
D _T	0.011 (0.61)	0.351 (14.05*)

Table 3.10 Yen Intraday Patterns of Depth and Spread

This table presents the coefficient estimates for the following models:

$$\text{Model 1: } \text{Depth}_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 2: } \text{Depth}_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

$$\text{Model 3: } \text{Spread}_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 4: } \text{Spread}_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

Depth is calculated as the sum of the depth available across all five levels. Spread is calculated as the sum of the depth-weighted spreads across all five levels. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. Models 1 and 3 employ data based on five-minute intervals. Models 2 and 4 employ data based on fifteen-minute intervals. Each regression is estimated separately for the day and night period. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

	Day	Night
Panel A: Model 1		
Intercept	558.671 (112.29*)	367.285 (166.73*)
D ₁	-17.683 (-1.06)	-217.12 (-50.89*)
D ₂	-110.98 (-7.54*)	-186.72 (-31.34*)
D ₃	-99.874 (-6.50*)	-163.00 (-23.50*)
D ₄	-17.993 (-1.06)	-145.56 (-19.22*)
D ₅	9.067 (0.53)	-134.05 (-17.24*)
D ₆	15.160 (0.88)	-129.74 (-15.99*)
D _{T-5}	-80.292 (-5.29*)	-255.24 (-71.27*)
D _{T-4}	-76.901 (-5.05*)	-254.58 (-71.26*)
D _{T-3}	-72.903 (-4.68*)	-260.09 (-79.80*)
D _{T-2}	-82.683 (-5.35*)	-263.24 (-84.17*)
D _{T-1}	-84.230 (-5.45*)	-267.93 (-86.04*)
D _T	-78.099 (-5.02*)	-270.14 (-89.64*)
Panel B: Model 2		
Intercept	558.853 (67.56*)	366.195 (98.60*)
D ₁	-75.864 (-5.03*)	-188.95 (-31.23*)
D ₂	1.399 (0.08)	-135.49 (-17.05*)
D _{T-1}	-78.138 (-5.18*)	-257.05 (-58.95*)
D _T	-81.241 (-5.33*)	-267.48 (-65.12*)

Table 3.10 (Continued)

Panel C: Model 3		
Intercept	6.208 (946.45*)	6.305 (1083.00*)
D ₁	-0.114 (-4.69*)	1.411 (31.14*)
D ₂	-0.052 (-2.04**)	1.149 (24.88*)
D ₃	0.038 (1.63)	1.099 (22.81*)
D ₄	-0.065 (-2.91*)	1.081 (23.94*)
D ₅	-0.101 (-4.67*)	0.982 (22.11*)
D ₆	-0.089 (-4.06*)	0.968 (21.49*)
D _{T-5}	0.056 (2.37**)	1.050 (18.68*)
D _{T-4}	0.041 (1.76***)	1.060 (17.73*)
D _{T-3}	0.009 (0.36)	0.988 (16.81*)
D _{T-2}	0.047 (1.86***)	1.045 (19.03*)
D _{T-1}	0.036 (1.49)	1.136 (19.75*)
D _T	-0.033 (-1.40)	1.287 (22.15*)
Panel D: Model 4		
Intercept	6.208 (582.84*)	6.305 (670.68*)
D ₁	-0.041 (-1.80***)	1.197 (31.38*)
D ₂	-0.084 (-4.01*)	1.002 (25.77*)
D _{T-1}	0.032 (1.40)	1.068 (21.27*)
D _T	0.000 (0.00)	1.174 (24.23*)

Table 3.11 Gold Intraday Patterns of Depth and Spread

This table presents the coefficient estimates for the following models:

$$\text{Model 1: } \text{Depth}_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 2: } \text{Depth}_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

$$\text{Model 3: } \text{Spread}_t = \alpha_0 + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 4: } \text{Spread}_t = \alpha_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

Depth is calculated as the sum of the depth available across all five levels. Spread is calculated as the sum of the depth-weighted spreads across all five levels. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. Models 1 and 3 employ data based on five-minute intervals. Models 2 and 4 employ data based on fifteen-minute intervals. Each regression is estimated separately for the day and night period. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

	Day	Night
Panel A: Model 1		
Intercept	106.101 (143.67*)	71.797 (247.91*)
D ₁	0.387 (0.16)	-25.981 (-14.63*)
D ₂	-12.388 (-5.84*)	-23.834 (-11.64*)
D ₃	-12.083 (-5.43*)	-25.056 (-15.61*)
D ₄	-3.996 (-1.72***)	-26.096 (-15.63*)
D ₅	-3.950 (-1.74***)	-25.630 (-15.94*)
D ₆	-2.769 (-1.24)	-25.647 (-14.79*)
D _{T-5}	-8.205 (-3.55*)	-17.707 (-9.22*)
D _{T-4}	-5.601 (-2.34**)	-14.669 (-6.76*)
D _{T-3}	-4.039 (-1.55)	-17.815 (-9.50*)
D _{T-2}	-3.304 (-1.32)	-16.810 (-8.06*)
D _{T-1}	-0.809 (-0.31)	-15.345 (-7.23*)
D _T	13.038 (4.79*)	-15.743 (-7.41*)
Panel B: Model 2		
Intercept	105.786 (90.00*)	71.468 (159.92*)
D ₁	-7.877 (-3.79*)	-24.965 (-17.35*)
D ₂	-3.416 (-1.63)	-25.017 (-16.70*)
D _{T-1}	-4.256 (-1.91***)	-15.947 (-8.65*)
D _T	6.460 (2.58*)	-15.515 (-8.12*)

Table 3.11 (Continued)

Panel C: Model 3		
Intercept	6.366 (702.04*)	7.678 (618.70*)
D ₁	-0.156 (-4.88*)	3.196 (32.09*)
D ₂	-0.071 (-2.09**)	2.606 (26.42*)
D ₃	0.038 (1.24)	2.684 (25.24*)
D ₄	-0.091 (-3.09*)	2.510 (24.57*)
D ₅	-0.078 (-2.90*)	2.618 (23.69*)
D ₆	-0.073 (-2.66*)	2.502 (21.89*)
D _{T-5}	0.086 (2.47**)	0.894 (7.92*)
D _{T-4}	0.044 (1.30)	0.987 (8.56*)
D _{T-3}	0.056 (1.46)	1.255 (11.35*)
D _{T-2}	-0.015 (-0.47)	2.097 (17.10*)
D _{T-1}	-0.035 (-1.04)	1.822 (15.01*)
D _T	-0.125 (-3.40*)	2.005 (18.53*)
Panel D: Model 4		
Intercept	6.368 (438.15*)	7.706 (393.13*)
D ₁	-0.063 (-2.21**)	2.716 (33.32*)
D ₂	-0.084 (-3.32*)	2.496 (28.54*)
D _{T-1}	0.030 (0.94)	1.045 (11.03*)
D _T	-0.083 (-2.57**)	2.002 (20.45*)

Table 3.12 T-note Depth Spread Relation

This table presents the coefficient estimates for the following models:

$$\text{Model 1: } \text{Depth}_t = \alpha_0 + \beta_0 \text{Spread} + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t + \varepsilon_i$$

$$\text{Model 2: } \text{Depth}_t = \alpha_0 + \beta_0 \text{Spread} + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

$$\text{Model 3: } \text{Depth}_t = \alpha_0 + \gamma_1 \text{Spread} + \gamma_2 \text{Volume}_t + \gamma_3 \text{Level}_t + \gamma_4 \text{Volatility}_t + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 4: } \text{Depth}_t = \alpha_0 + \gamma_1 \text{Spread} + \gamma_2 \text{Volume}_t + \gamma_3 \text{Level}_t + \gamma_4 \text{Volatility}_t + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

Depth is calculated as the sum of the depth available across all five levels. Spread is calculated as the sum of the depth-weighted spreads across all five levels. Volume is computed as the sum of trade volume in each time interval. Level is represented by the mean trade price in each time interval. Volatility is defined by the standard deviation of trade prices in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. Models 1 and 3 employ data based on five-minute intervals. Models 2 and 4 employ data based on fifteen-minute intervals. Each regression is estimated separately for the day and night period. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

	Day	Night
Panel A: Model 1		
Intercept	-19003 (-15.57*)	2783.95 (8.59*)
Spread	316991 (22.47*)	13461.4 (3.69*)
D ₁	-596.88 (-2.47**)	-2599.8 (-31.26*)
D ₂	-1728.7 (-7.13*)	-2307.2 (-21.46*)
D ₃	-1014.2 (-4.10*)	-2180.3 (-18.88*)
D ₄	338.887 (1.24)	-2125.6 (-17.69*)
D ₅	609.661 (2.19**)	-2112.4 (-17.36*)
D ₆	598.301 (2.15**)	-2048.6 (-17.55*)
D _{T-5}	-1188.6 (-4.67*)	685.299 (3.61*)
D _{T-4}	-1129.2 (-4.26*)	635.013 (3.34*)
D _{T-3}	-1103.6 (-4.20*)	415.128 (2.34**)
D _{T-2}	-1105.4 (-4.19*)	273.329 (1.57)
D _{T-1}	-1096.1 (-4.12*)	23.326 (0.14)
D _T	-690.17 (-2.50**)	-402.33 (-2.62*)
Panel B: Model 2		
Intercept	-29145 (-12.05*)	2037.06 (3.49*)
Spread	434837 (15.55*)	21514.7 (3.27*)
D ₁	-880.57 (-3.79*)	-2419.9 (-24.23*)
D ₂	676.979 (2.58**)	-2103.6 (-17.57*)
D _{T-1}	-1235.7 (-4.89*)	642.066 (3.49*)
D _T	-895.97 (-3.36*)	-4.902 (-0.03)

Table 3.12 (Continued)

Panel C: Model 3		
Intercept	13537.5 (4.48*)	11147.9 (8.91*)
Spread	293357 (23.82*)	40318.8 (11.66*)
Volume	0.329 (27.53*)	0.671 (19.28*)
Level	-262.21 (-11.64*)	-95.738 (-9.15*)
Volatility	-129542 (-15.32*)	-37637 (-5.34*)
D ₁	-669.29 (-3.25*)	-2199.5 (-21.26*)
D ₂	-956.78 (-4.73*)	-1781.2 (-15.76*)
D ₃	-1926.3 (-6.86*)	-1648.3 (-13.00*)
D ₄	-615.04 (-2.58*)	-1617.0 (-12.59*)
D ₅	-25.727 (-0.11)	-1649.8 (-13.85*)
D ₆	190.551 (0.78)	-1538.6 (-11.94*)
D _{T-5}	-579.83 (-2.75*)	695.627 (3.90*)
D _{T-4}	-451.41 (-2.01**)	639.612 (3.61*)
D _{T-3}	-503.43 (-2.27**)	459.475 (2.84*)
D _{T-2}	-603.49 (-2.70*)	376.374 (2.41**)
D _{T-1}	-668.83 (-2.92*)	155.782 (1.02)
D _T	-833.26 (-3.35*)	-386.27 (-2.85*)
Panel D: Model 4		
Intercept	2471.45 (0.51)	8171.71 (4.21*)
Spread	368225 (16.35*)	60357.0 (10.10*)
Volume	0.153 (27.71*)	0.334 (16.41*)
Level	-227.89 (-6.69*)	-84.130 (-5.20*)
Volatility	-85891 (-23.53*)	-50895 (-6.36*)
D ₁	-357.13 (-1.75***)	-1589.9 (-13.23*)
D ₂	-436.20 (-1.84***)	-1416.9 (-10.95*)
D _{T-1}	-432.44 (-2.01**)	641.567 (3.94*)
D _T	-119.83 (-0.53)	103.174 (0.78)

Table 3.13 Corn Depth Spread Relation

This table presents the coefficient estimates for the following models:

$$\text{Model 1: } \text{Depth}_t = \alpha_0 + \beta_0 \text{Spread} + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t + \varepsilon_i$$

$$\text{Model 2: } \text{Depth}_t = \alpha_0 + \beta_0 \text{Spread} + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

$$\text{Model 3: } \text{Depth}_t = \alpha_0 + \gamma_1 \text{Spread} + \gamma_2 \text{Volume}_t + \gamma_3 \text{Level}_t + \gamma_4 \text{Volatility}_t + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 4: } \text{Depth}_t = \alpha_0 + \gamma_1 \text{Spread} + \gamma_2 \text{Volume}_t + \gamma_3 \text{Level}_t + \gamma_4 \text{Volatility}_t + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

Depth is calculated as the sum of the depth available across all five levels. Spread is calculated as the sum of the depth-weighted spreads across all five levels. Volume is computed as the sum of trade volume in each time interval. Level is represented by the mean trade price in each time interval. Volatility is defined by the standard deviation of trade prices in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. Models 1 and 3 employ data based on five-minute intervals. Models 2 and 4 employ data based on fifteen-minute intervals. Each regression is estimated separately for the day and night period. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

	Day	Night
Panel A: Model 1		
Intercept	832.777 (15.40*)	353.100 (39.70*)
Spread	-197.40 (-5.11*)	-80.232 (-19.42*)
D ₁	-74.036 (-5.91*)	46.441 (4.95*)
D ₂	-17.044 (-1.20)	25.489 (2.88*)
D ₃	9.570 (0.67)	30.021 (3.06*)
D ₄	16.824 (1.10)	34.535 (3.33*)
D ₅	11.554 (0.81)	29.825 (2.90*)
D ₆	23.854 (1.54)	28.197 (2.69*)
D _{T-5}	-12.168 (-0.82)	-13.222 (-1.56)
D _{T-4}	-6.398 (-0.44)	-10.354 (-1.20)
D _{T-3}	-9.967 (-0.64)	-12.371 (-1.42)
D _{T-2}	-10.408 (-0.63)	-6.518 (-0.72)
D _{T-1}	16.524 (0.98)	0.568 (0.06)
D _T	50.862 (2.98*)	3.247 (0.35)
Panel B: Model 2		
Intercept	991.120 (9.05*)	389.108 (25.33*)
Spread	-312.27 (-3.96*)	-99.269 (-14.00*)
D ₁	-26.053 (-2.14**)	27.942 (3.12*)
D ₂	16.235 (1.24)	24.837 (2.48**)
D _{T-1}	-6.771 (-0.51)	-14.488 (-1.84***)
D _T	25.313 (1.67***)	-2.311 (-0.28)

Table 3.13 (Continued)

Panel C: Model 3		
Intercept	888.103 (19.41*)	389.062 (32.66*)
Spread	8.089 (0.25)	-68.376 (-16.88*)
Volume	0.068 (19.14*)	0.179 (12.42*)
Level	-0.516 (-16.90*)	-0.084 (-6.38*)
Volatility	-332.98 (-26.57*)	-113.71 (-18.36*)
D ₁	-204.75 (-9.36*)	-64.509 (-4.11*)
D ₂	-52.375 (-3.75*)	2.772 (0.29)
D ₃	-0.325 (-0.02)	17.827 (1.78***)
D ₄	4.532 (0.34)	26.983 (2.64*)
D ₅	1.503 (0.12)	28.035 (2.76*)
D ₆	16.723 (1.29)	26.133 (2.56**)
D _{T-5}	-9.878 (-0.78)	-12.463 (-1.49)
D _{T-4}	3.286 (0.27)	-9.321 (-1.09)
D _{T-3}	-0.457 (-0.04)	-11.443 (-1.34)
D _{T-2}	-5.768 (-0.43)	-2.607 (-0.29)
D _{T-1}	19.841 (1.38)	4.075 (0.47)
D _T	2.056 (0.12)	7.045 (0.78)
Panel D: Model 4		
Intercept	939.013 (11.67*)	414.842 (21.13*)
Spread	-33.624 (-0.58)	-78.658 (-11.41*)
Volume	0.025 (11.89*)	0.109 (10.80*)
Level	-0.527 (-11.70*)	-0.076 (-3.88*)
Volatility	-190.92 (-17.77*)	-115.60 (-15.80*)
D ₁	-112.51 (-5.51*)	-52.063 (-3.76*)
D ₂	-5.843 (-0.49)	16.669 (1.70***)
D _{T-1}	0.767 (0.07)	-11.708 (-1.55)
D _T	15.020 (1.03)	1.641 (0.20)

Table 3.14 Oil Depth Spread Relation

This table presents the coefficient estimates for the following models:

$$\text{Model 1: } \text{Depth}_t = \alpha_0 + \beta_0 \text{Spread} + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t + \varepsilon_t$$

$$\text{Model 2: } \text{Depth}_t = \alpha_0 + \beta_0 \text{Spread} + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

$$\text{Model 3: } \text{Depth}_t = \alpha_0 + \gamma_1 \text{Spread} + \gamma_2 \text{Volume}_t + \gamma_3 \text{Level}_t + \gamma_4 \text{Volatility}_t + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 4: } \text{Depth}_t = \alpha_0 + \gamma_1 \text{Spread} + \gamma_2 \text{Volume}_t + \gamma_3 \text{Level}_t + \gamma_4 \text{Volatility}_t + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

Depth is calculated as the sum of the depth available across all five levels. Spread is calculated as the sum of the depth-weighted spreads across all five levels. Volume is computed as the sum of trade volume in each time interval. Level is represented by the mean trade price in each time interval. Volatility is defined by the standard deviation of trade prices in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. Models 1 and 3 employ data based on five-minute intervals. Models 2 and 4 employ data based on fifteen-minute intervals. Each regression is estimated separately for the day and night period. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

	Day	Night
Panel A: Model 1		
Intercept	344.447 (25.98*)	103.005 (107.20*)
Spread	-32.790 (-18.32*)	-5.604 (-65.96*)
D ₁	-4.661 (-2.31**)	11.434 (7.65*)
D ₂	-2.918 (-1.45)	6.310 (5.23*)
D ₃	-2.063 (-1.00)	6.868 (5.29*)
D ₄	-1.800 (-0.88)	6.513 (4.77*)
D ₅	-1.470 (-0.74)	7.082 (5.21*)
D ₆	-2.084 (-1.06)	6.392 (4.49*)
D _{T-5}	-0.847 (-0.45)	5.034 (3.48*)
D _{T-4}	-0.783 (-0.45)	4.678 (3.07*)
D _{T-3}	0.172 (0.10)	4.519 (3.31*)
D _{T-2}	1.977 (1.01)	5.133 (3.50*)
D _{T-1}	2.853 (1.44)	3.808 (2.60*)
D _T	14.561 (7.86*)	5.254 (3.59*)
Panel B: Model 2		
Intercept	361.089 (16.65*)	109.051 (68.29*)
Spread	-35.054 (-11.98*)	-6.215 (-43.29*)
D ₁	-3.341 (-1.78***)	10.164 (9.68*)
D ₂	-1.934 (-1.05)	8.386 (7.14*)
D _{T-1}	0.109 (0.07)	5.214 (4.21*)
D _T	6.283 (3.65*)	6.112 (4.51*)

Table 3.14 (Continued)

Panel C: Model 3		
Intercept	342.494 (23.55*)	83.505 (82.34*)
Spread	-34.397 (-16.16*)	-4.755 (-58.77*)
Volume	0.000 (4.06*)	0.007 (20.57*)
Level	0.222 (12.95*)	0.098 (20.23*)
Volatility	-76.746 (-8.03*)	-13.535 (-4.50*)
D ₁	-4.605 (-2.40**)	11.216 (7.68*)
D ₂	-2.959 (-1.54)	6.610 (5.70*)
D ₃	-1.948 (-0.99)	7.127 (5.69*)
D ₄	-1.966 (-1.00)	6.770 (5.20*)
D ₅	-1.703 (-0.91)	7.334 (5.60*)
D ₆	-2.474 (-1.33)	6.804 (4.94*)
D _{T-5}	0.367 (0.20)	7.022 (4.94*)
D _{T-4}	-0.031 (-0.02)	6.747 (4.51*)
D _{T-3}	1.709 (0.98)	6.461 (4.81*)
D _{T-2}	3.370 (1.76***)	6.961 (4.84*)
D _{T-1}	3.933 (2.03**)	5.383 (3.81*)
D _T	13.319 (6.41*)	6.513 (4.54*)
Panel D: Model 4		
Intercept	349.961 (14.55*)	88.197 (55.94*)
Spread	-35.647 (-10.16*)	-5.143 (-39.90*)
Volume	0.000 (4.53*)	0.003 (16.59*)
Level	0.240 (8.62*)	0.097 (14.12*)
Volatility	-77.901 (-6.96*)	-24.038 (-4.76*)
D ₁	-3.384 (-1.93***)	9.663 (9.52*)
D ₂	-2.430 (-1.42)	8.131 (7.29*)
D _{T-1}	0.445 (0.27)	7.050 (5.81*)
D _T	2.526 (1.02)	7.393 (5.60*)

Table 3.15 Euro Depth Spread Relation

This table presents the coefficient estimates for the following models:

$$\text{Model 1: } \text{Depth}_t = \alpha_0 + \beta_0 \text{Spread} + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t + \varepsilon_i$$

$$\text{Model 2: } \text{Depth}_t = \alpha_0 + \beta_0 \text{Spread} + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

$$\text{Model 3: } \text{Depth}_t = \alpha_0 + \gamma_1 \text{Spread} + \gamma_2 \text{Volume}_t + \gamma_3 \text{Level}_t + \gamma_4 \text{Volatility}_t + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 4: } \text{Depth}_t = \alpha_0 + \gamma_1 \text{Spread} + \gamma_2 \text{Volume}_t + \gamma_3 \text{Level}_t + \gamma_4 \text{Volatility}_t + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

Depth is calculated as the sum of the depth available across all five levels. Spread is calculated as the sum of the depth-weighted spreads across all five levels. Volume is computed as the sum of trade volume in each time interval. Level is represented by the mean trade price in each time interval. Volatility is defined by the standard deviation of trade prices in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. Models 1 and 3 employ data based on five-minute intervals. Models 2 and 4 employ data based on fifteen-minute intervals. Each regression is estimated separately for the day and night period. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

	Day	Night
Panel A: Model 1		
Intercept	3608.38 (83.14*)	1672.00 (125.67*)
Spread	-477.54 (-70.64*)	-202.61 (-103.74*)
D ₁	-69.708 (-5.80*)	-167.74 (-26.07*)
D ₂	-158.31 (-13.99*)	-102.96 (-14.94*)
D ₃	-128.81 (-11.66*)	-56.036 (-7.66*)
D ₄	-62.126 (-5.45*)	-48.011 (-6.70*)
D ₅	-38.870 (-3.32*)	-37.313 (-5.51*)
D ₆	-23.156 (-1.99**)	-29.834 (-4.51*)
D _{T-5}	-59.854 (-5.21*)	-161.19 (-26.72*)
D _{T-4}	-62.242 (-5.51*)	-152.86 (-23.43*)
D _{T-3}	-66.718 (-5.89*)	-158.61 (-25.12*)
D _{T-2}	-82.770 (-7.16*)	-156.40 (-25.72*)
D _{T-1}	-92.561 (-7.78*)	-167.12 (-27.04*)
D _T	-101.91 (-8.57*)	-178.29 (-27.42*)
Panel B: Model 2		
Intercept	3776.38 (51.01*)	1794.18 (78.81*)
Spread	-504.79 (-43.75*)	-222.12 (-66.29*)
D ₁	-120.84 (-11.08*)	-96.170 (-15.81*)
D ₂	-43.666 (-3.93*)	-27.875 (-4.60*)
D _{T-1}	-68.329 (-6.31*)	-149.47 (-25.86*)
D _T	-95.921 (-8.33*)	-161.23 (-30.53*)

Table 3.15 (Continued)

Panel C: Model 3		
Intercept	-117.92 (-1.56)	-470.95 (-17.46*)
Spread	-241.66 (-31.77*)	-98.789 (-47.53*)
Volume	0.006 (7.32*)	0.034 (22.06*)
Level	159.189 (58.51*)	102.959 (82.37*)
Volatility	-2772.6 (-7.33*)	-554.38 (-6.07*)
D ₁	-34.428 (-3.45*)	-169.21 (-27.14*)
D ₂	-133.62 (-13.10*)	-115.26 (-19.08*)
D ₃	-128.01 (-12.32*)	-83.407 (-14.73*)
D ₄	-45.278 (-4.68*)	-73.990 (-13.38*)
D ₅	-18.783 (-1.97**)	-64.640 (-12.28*)
D ₆	-3.382 (-0.36)	-56.591 (-11.20*)
D _{T-5}	-74.455 (-7.60*)	-174.25 (-30.13*)
D _{T-4}	-72.221 (-7.47*)	-169.95 (-28.02*)
D _{T-3}	-74.915 (-7.67*)	-176.20 (-28.93*)
D _{T-2}	-85.019 (-8.56*)	-178.07 (-29.58*)
D _{T-1}	-93.392 (-9.20*)	-183.44 (-30.12*)
D _T	-97.286 (-9.66*)	-199.38 (-30.68*)
Panel D: Model 4		
Intercept	-22.630 (-0.18)	-383.87 (-8.29*)
Spread	-245.44 (-18.57*)	-105.50 (-28.58*)
Volume	0.004 (6.95*)	0.014 (16.88*)
Level	154.104 (34.10*)	99.419 (48.74*)
Volatility	-4333.8 (-5.23*)	-1011.9 (-4.86*)
D ₁	-96.322 (-10.11*)	-113.90 (-20.80*)
D ₂	-26.633 (-2.88*)	-56.769 (-11.44*)
D _{T-1}	-72.275 (-7.86*)	-162.46 (-27.99*)
D _T	-87.405 (-8.81*)	-176.76 (-30.65*)

Table 3.16 Yen Depth Spread Relation

This table presents the coefficient estimates for the following models:

$$\text{Model 1: } \text{Depth}_t = \alpha_0 + \beta_0 \text{Spread} + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t + \varepsilon_i$$

$$\text{Model 2: } \text{Depth}_t = \alpha_0 + \beta_0 \text{Spread} + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

$$\text{Model 3: } \text{Depth}_t = \alpha_0 + \gamma_1 \text{Spread} + \gamma_2 \text{Volume}_t + \gamma_3 \text{Level}_t + \gamma_4 \text{Volatility}_t + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 4: } \text{Depth}_t = \alpha_0 + \gamma_1 \text{Spread} + \gamma_2 \text{Volume}_t + \gamma_3 \text{Level}_t + \gamma_4 \text{Volatility}_t + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

Depth is calculated as the sum of the depth available across all five levels. Spread is calculated as the sum of the depth-weighted spreads across all five levels. Volume is computed as the sum of trade volume in each time interval. Level is represented by the mean trade price in each time interval. Volatility is defined by the standard deviation of trade prices in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. Models 1 and 3 employ data based on five-minute intervals. Models 2 and 4 employ data based on fifteen-minute intervals. Each regression is estimated separately for the day and night period. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

	Day	Night
Panel A: Model 1		
Intercept	3165.41 (67.16*)	1330.27 (98.92*)
Spread	-419.88 (-57.48*)	-152.73 (-79.17*)
D ₁	-65.341 (-4.97*)	-1.599 (-0.24)
D ₂	-132.80 (-10.61*)	-11.231 (-1.55)
D ₃	-83.861 (-6.82*)	4.855 (0.62)
D ₄	-45.090 (-3.35*)	19.556 (2.62*)
D ₅	-33.539 (-2.44**)	15.976 (2.11**)
D ₆	-22.345 (-1.66***)	18.179 (2.27**)
D _{T-5}	-56.592 (-4.68*)	-94.794 (-12.01*)
D _{T-4}	-59.714 (-4.82*)	-92.678 (-11.08*)
D _{T-3}	-69.074 (-5.49*)	-109.15 (-13.01*)
D _{T-2}	-63.086 (-5.07*)	-103.63 (-13.28*)
D _{T-1}	-68.983 (-5.45*)	-94.439 (-11.52*)
D _T	-92.003 (-7.44*)	-73.608 (-8.45*)
Panel B: Model 2		
Intercept	3312.76 (40.97*)	1426.00 (60.26*)
Spread	-443.61 (-35.37*)	-168.09 (-49.45*)
D ₁	-93.864 (-7.73*)	12.200 (1.89***)
D ₂	-35.821 (-2.76*)	32.930 (4.71*)
D _{T-1}	-64.006 (-5.34*)	-77.585 (-9.90*)
D _T	-81.231 (-6.65*)	-70.101 (-8.91*)

Table 3.16 (Continued)

Panel C: Model 3		
Intercept	4780.25 (92.99*)	3018.08 (113.90*)
Spread	-188.02 (-27.45*)	-76.836 (-47.68*)
Volume	0.019 (10.72*)	0.041 (15.80*)
Level	-303076 (-56.71*)	-215087 (-85.95*)
Volatility	-5.19E6 (-6.34*)	-3.5E6 (-8.03*)
D ₁	-46.965 (-4.28*)	-99.955 (-14.15*)
D ₂	-116.58 (-10.86*)	-88.187 (-13.35*)
D ₃	-115.62 (-10.15*)	-68.142 (-10.90*)
D ₄	-45.673 (-4.03*)	-52.064 (-8.55*)
D ₅	-20.131 (-1.80***)	-47.581 (-7.92*)
D ₆	-7.979 (-0.74)	-43.417 (-7.15*)
D _{T-5}	-62.761 (-6.12*)	-162.09 (-19.17*)
D _{T-4}	-59.850 (-5.72*)	-162.63 (-18.61*)
D _{T-3}	-65.083 (-6.08*)	-170.61 (-19.65*)
D _{T-2}	-67.280 (-6.35*)	-174.04 (-20.72*)
D _{T-1}	-69.535 (-6.46*)	-172.41 (-20.15*)
D _T	-89.616 (-8.53*)	-161.90 (-18.32*)
Panel D: Model 4		
Intercept	4599.47 (51.73*)	2962.23 (67.84*)
Spread	-178.15 (-14.37*)	-79.492 (-27.42*)
Volume	0.012 (9.78*)	0.021 (11.79*)
Level	-291173 (-32.38*)	-207768 (-50.88*)
Volatility	-9.26E6 (-6.90*)	-5.31E6 (-6.91*)
D ₁	-87.120 (-8.33*)	-76.187 (-11.96*)
D ₂	-32.173 (-3.00*)	-39.092 (-6.60*)
D _{T-1}	-57.626 (-5.77*)	-144.70 (-16.81*)
D _T	-68.193 (-6.65*)	-147.70 (-17.30*)

Table 3.17 Gold Depth Spread Relation

This table presents the coefficient estimates for the following models:

$$\text{Model 1: } \text{Depth}_t = \alpha_0 + \beta_0 \text{Spread} + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t + \varepsilon_i$$

$$\text{Model 2: } \text{Depth}_t = \alpha_0 + \beta_0 \text{Spread} + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

$$\text{Model 3: } \text{Depth}_t = \alpha_0 + \gamma_1 \text{Spread} + \gamma_2 \text{Volume}_t + \gamma_3 \text{Level}_t + \gamma_4 \text{Volatility}_t + \sum_{i=1}^6 \beta_i D_i + \sum_{i=T-5}^T \beta_i D_i + \varepsilon_t$$

$$\text{Model 4: } \text{Depth}_t = \alpha_0 + \gamma_1 \text{Spread} + \gamma_2 \text{Volume}_t + \gamma_3 \text{Level}_t + \gamma_4 \text{Volatility}_t + \beta_1 D_1 + \beta_2 D_2 + \beta_{T-1} D_{T-1} + \beta_T D_T + \varepsilon_t$$

Depth is calculated as the sum of the depth available across all five levels. Spread is calculated as the sum of the depth-weighted spreads across all five levels. Volume is computed as the sum of trade volume in each time interval. Level is represented by the mean trade price in each time interval. Volatility is defined by the standard deviation of trade prices in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. Models 1 and 3 employ data based on five-minute intervals. Models 2 and 4 employ data based on fifteen-minute intervals. Each regression is estimated separately for the day and night period. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

	Day	Night
Panel A: Model 1		
Intercept	399.362 (65.55*)	156.857 (145.63*)
Spread	-46.064 (-48.63*)	-11.079 (-86.39*)
D ₁	-6.814 (-3.56*)	9.429 (5.25*)
D ₂	-15.645 (-8.69*)	5.040 (2.49**)
D ₃	-10.323 (-5.72*)	4.685 (2.83*)
D ₄	-8.192 (-4.26*)	1.714 (0.98)
D ₅	-7.555 (-4.21*)	3.379 (1.96***)
D ₆	-6.151 (-3.40*)	2.070 (1.12)
D _{T-5}	-4.248 (-2.18**)	-7.798 (-3.97*)
D _{T-4}	-3.561 (-1.70***)	-3.739 (-1.75***)
D _{T-3}	-1.463 (-0.63)	-3.908 (-2.10**)
D _{T-2}	-4.016 (-1.88***)	6.423 (2.85*)
D _{T-1}	-2.409 (-1.01)	4.836 (2.10**)
D _T	7.271 (3.16*)	6.468 (3.02*)
Panel B: Model 2		
Intercept	444.490 (41.07*)	167.514 (95.22*)
Spread	-53.185 (-31.45*)	-12.464 (-58.29*)
D ₁	-11.230 (-7.14*)	8.886 (5.81*)
D ₂	-7.865 (-5.05*)	6.089 (3.84*)
D _{T-1}	-2.676 (-1.42)	-2.923 (-1.69***)
D _T	2.049 (0.94)	9.441 (4.75*)

Table 3.17 (Continued)

Panel C: Model 3		
Intercept	269.098 (25.00*)	53.828 (15.93*)
Spread	-40.442 (-40.82*)	-9.314 (-68.82*)
Volume	0.003 (15.71*)	0.006 (16.00*)
Level	0.999 (13.39*)	0.992 (30.36*)
Volatility	-18.724 (-2.26**)	-10.553 (-3.40*)
D ₁	-10.461 (-5.67*)	4.770 (2.73*)
D ₂	-15.903 (-9.53*)	2.143 (1.07)
D ₃	-14.175 (-8.05*)	1.718 (1.07)
D ₄	-10.839 (-5.81*)	-0.969 (-0.56)
D ₅	-9.407 (-5.41*)	0.604 (0.36)
D ₆	-6.691 (-3.85*)	-0.425 (-0.24)
D _{T-5}	-2.088 (-1.13)	-7.651 (-4.01*)
D _{T-4}	-1.028 (-0.51)	-3.817 (-1.82***)
D _{T-3}	0.930 (0.42)	-4.382 (-2.42**)
D _{T-2}	-1.388 (-0.67)	4.600 (2.12**)
D _{T-1}	0.258 (0.11)	3.420 (1.53)
D _T	6.079 (2.72*)	4.683 (2.22**)
Panel D: Model 4		
Intercept	329.926 (18.02*)	74.759 (14.60*)
Spread	-46.794 (-25.15*)	-10.604 (-45.99*)
Volume	0.001 (8.92*)	0.002 (8.39*)
Level	0.762 (6.49*)	0.873 (18.22*)
Volatility	-29.177 (-2.13**)	-18.323 (-3.41*)
D ₁	-14.187 (-9.33*)	5.580 (3.78*)
D ₂	-9.885 (-6.46*)	3.229 (2.09**)
D _{T-1}	0.223 (0.13)	-3.270 (-1.92***)
D _T	5.360 (2.56**)	7.492 (3.87*)

Figure 3.1 Distribution of T-Note Futures Best Spread (Top) and Total Spread (Bottom)

This figure presents the distribution of the best spread for day and night in the top panel and the distribution of the total spread for day and night in the bottom panel. The distribution is generated using five-minute intervals.

Figure 3.2 Distribution of Corn Futures Best Spread (Top) and Total Spread (Bottom)

This figure presents the distribution of the best spread for day and night in the top panel and the distribution of the total spread for day and night in the bottom panel. The distribution is generated using five-minute intervals.

Figure 3.3 Distribution of Oil Futures Best Spread (Top) and Total Spread (Bottom)

This figure presents the distribution of the best spread for day and night in the top panel and the distribution of the total spread for day and night in the bottom panel. The distribution is generated using five-minute intervals.

Figure 3.4 Distribution of Euro Futures Best Spread (Top) and Total Spread (Bottom)

This figure presents the distribution of the best spread for day and night in the top panel and the distribution of the total spread for day and night in the bottom panel. The distribution is generated using five-minute intervals.

Figure 3.5 Distribution of Yen Futures Best Spread (Top) and Total Spread (Bottom)

This figure presents the distribution of the best spread for day and night in the top panel and the distribution of the total spread for day and night in the bottom panel. The distribution is generated using five-minute intervals.

Figure 3.6 Distribution of Gold Futures Best Spread (Top) and Total Spread (Bottom)

This figure presents the distribution of the best spread for day and night in the top panel and the distribution of the total spread for day and night in the bottom panel. The distribution is generated using five-minute intervals.

Figure 3.7 T-note Futures Depth and Spread Behavior

This figure presents the behavior of the depth and spread over the day using five-minute intervals.

Figure 3.8 Corn Futures Depth and Spread Behavior

This figure presents the behavior of the depth and spread over the day using five-minute intervals.

Figure 3.9 Oil Futures Depth and Spread Behavior

This figure presents the behavior of the depth and spread over the day using five-minute intervals.

Figure 3.10 Euro Futures Depth and Spread Behavior

This figure presents the behavior of the depth and spread over the day using five-minute intervals.

Figure 3.11 Yen Futures Depth and Spread Behavior

This figure presents the behavior of the depth and spread over the day using five-minute intervals.

Figure 3.12 Gold Futures Depth and Spread Behavior

This figure presents the behavior of the depth and spread over the day using five-minute intervals.

CHAPTER 4: THE RELATION BETWEEN DEPTH AND VOLATILITY

4.1. Introduction

This chapter delves into the topic of the relation between depth and volatility in U.S. electronic futures market. Although the relation between depth and volatility has been studied for stock markets and international futures markets, similar research is lacking for U.S. futures markets, for more than the best bid-ask depth, and for night trading. Furthermore, the results of prior literature for other markets in this area remain inconclusive. For example, Ahn, Bae, and Chan (2001) find a positive relation between market depth and transitory volatility for equities on the Stock Exchange of Hong Kong (SEHK), whereas Chen and Wu (2009) support a negative relation for the Taiwan Futures Exchange (TAIFEX).

The objective of this chapter is to investigate the relation between depth and transitory (lagged) volatility using a unique dataset of electronic five deep depth data for U.S. futures contracts. This examination differs from previous research in several ways. The focus in this chapter is on U.S. futures markets, whereas prior research emphasizes stocks and international futures markets. In addition, I examine the depth and transitory volatility relation during both the traditional (day) and night hours, whereas all prior literature limits the examination of the depth-volatility relation to the traditional day (open outcry or floor trading) trading hours for non-U.S. markets. Finally, I employ the five deep depth data for the futures contracts rather than the typical best bid-ask depth data.

The analysis in this chapter is based on the theory developed by Handa and Schwartz (1996). They derive a model where investors have a choice between market and

limit orders. This choice is driven by the investors' beliefs about the probability of order execution against a liquidity trader versus an informed trader. Handa and Schwartz (1996) show that when price volatility is high, more limit orders than market orders are submitted by investors because the expected gain trading against liquidity traders outweighs the expected loss trading against informed traders. Therefore, in a period of high volatility, more limit orders are placed.

Additionally, Foucault (1999) derives a model with a different rationale compared to Handa and Schwartz (1996), but arrives at the same conclusion. In particular, he shows that when volatility increases, the submission of market orders becomes more costly and therefore more limit orders are submitted. The implication is that the number of limit orders increases with more volatility.

The models of both Handa and Schwartz (1996) and Foucault (1999) predict an increase in the number of limit orders placed when volatility increases. As a result, if more limit orders are placed, the available depth should increase as well.

4.2. Literature Review

The early literature on the depth-volatility relation employs open interest as a proxy for market depth.¹⁷ One of the first research articles to examine the relation between depth and volatility using actual depth data is Ahn, Bae, and Chan (2001). They examine the intraday depth-volatility relation for SEHK stocks by using the total number of limit orders outstanding in the five-deep limit order book, as the measure of depth. They find that a rise in transitory volatility leads to an increase in market depth after

¹⁷ For example, Bessembinder and Seguin (1993) employ eight futures contracts to find an inverse relation between volatility and market depth. Fung and Patterson (2001) also find an inverse relation between market depth and volatility for currency and interest rate futures contracts. Both studies employ open interest as a proxy for market depth.

controlling for the frequency of trades, intraday variation in market depth, and the autocorrelation in market depth. In other words, a positive relation between depth and lagged volatility is reported.

Vo (2007) finds that lagged price volatility is negatively related to market depth for Toronto Stock Exchange (TSE) stocks using the best depth. Chen and Wu (2009) find that a rise in volatility is followed by a decrease in market depth for a five-deep depth sample from the Taiwan Futures Exchange (TAIFEX), using the number of limit orders as their measure of depth.

Chiang, Lin, and Yu (2009) study the relation between depth and transitory volatility, separating their TAIFEX futures data into bull and bear market periods. They find evidence of a positive relation between depth and lagged volatility during bull markets and a negative relation during bear markets.

Overall, the majority of past research for both equity and futures markets find an inverse relation between depth and volatility. Only Ahn, Bae, and Chan (2001) and Chiang, Lin, and Yu (2009) find evidence of a positive relation between transitory volatility and depth. However, evidence of the relation between transitory volatility and depth using actual depth data for U.S. futures markets is an unexplored topic and furthermore past studies do not consider the night period.

4.3. Data

I use six electronically traded futures contracts (the T-note, corn, oil, euro, yen, and gold futures) in this study to examine the effect of transitory volatility on depth for all of 2008 and the beginning of 2009. The trading days for each futures contract are partitioned into both five-minute and fifteen-minute intervals, with the analysis

performed separately for each time interval. The decoded RLC depth messages are sampled at the beginning of each second and averaged over the five- and fifteen-minute time intervals. The futures contracts are rolled over when trading volume in a deferred expiration exceeds the trading volume in the near-term expiration. The daily trading hours are partitioned into day trading (open outcry portion) and night trading (non-open outcry portion).¹⁸

4.4. Methodology

4.4.1. Variables

In this section I describe the variables that are employed in the analysis and then form the research hypotheses based on theoretical considerations. Similar to Chiang, Lin, and Yu (2009), two measures of depth are used. The first depth measure is called “depth quantity” and is defined as the sum of the depth over the five levels in the limit order book. The second measure of depth is called “depth frequency” and is quantified as the sum of the number of limit orders over the five depth levels.

Three volatility measures are specified in order to assure that results are not dependent on any one measure of volatility. The first measure of volatility used is the Garman-Klass (GK) volatility measure proposed by Garman and Klass (1980). The GK volatility measure is often employed in volatility studies (for example see Daigler and Wiley (1999)), and is calculated as follows:

¹⁸ Missing values are possible in the calculation of the various volatility measures presented in the next section. All three measures are based on trade prices. Therefore if a given interval contains no trade prices, then the volatility measures can be undefined. In such a case, the previous volatility is used to replace the missing value. The longer fifteen-minute interval is less likely to have missing volatility data.

$$Var(GK) = \frac{1}{2} [\ln(High) - \ln(Low)]^2 - [2\ln(2) - 1] [\ln(Open) - \ln(Close)]^2 \quad (4.1)$$

where High represents the highest trade price, Low denotes the lowest price, Open designates the first price, and Close is the last trade price in a time interval. One important feature of the GK volatility is that it is about eight times more efficient than the traditional close-to-close volatility estimator. The GK volatility measures the volatility within a time interval and does not necessarily increase with more trades in an interval.

The second measure of volatility used is the returns volatility. The returns volatility is calculated as follows:

$$Returns\ Volatility = \left| \ln \left(\frac{Price_t}{Price_{t-1}} \right) \right| \quad (4.2)$$

where the $Price_t$ is the last trade price in time interval t and $Price_{t-1}$ is the last price in the preceding time interval.¹⁹ Unlike the GK volatility measure, the returns volatility calculates the volatility between time intervals rather than within time intervals. In addition, the returns volatility only samples a single (last) price in a time interval.

The third measure of volatility used is called the realized volatility and is featured in Ahn, Bae, and Chan (2001). The realized volatility is found as follows:

$$Realized\ Volatility = \sum_{i=1}^N R_{i,t}^2 \quad (4.4)$$

where $R_{i,t}$ is the return for the i th trade during the time interval t , and N is the total number of transactions within a time interval. The returns are calculated as the log difference of the sequential trade prices in a time interval. The sum of the squared returns

¹⁹ For the first interval of the day, $Price_t$ is the last trade price in the interval and $Price_{t-1}$ is the first trade price in the interval. The returns volatility measure is employed in various prior studies, such as ap Gwilym, McMillan, and Speight (1999).

in an interval is not divided by the total number of transactions because the cumulative price fluctuations are of interest.

4.4.2. Hypotheses

The models of Handa and Schwartz (1996) and Foucault (1999) motivate the research hypotheses examined in this chapter. Handa and Schwartz (1996) show that more limit orders than market orders are submitted by investors when price volatility is high. Foucault (1999) shows that when volatility increases, the submission of market orders becomes more costly and therefore more limit orders are submitted. These models motivate the following research hypothesis concerning volatility and depth:

Research hypothesis 1: A positive relation exists between transitory volatility and the quantity of depth.

Research hypothesis 2: A positive relation exists between transitory volatility and depth frequency.

In order to examine these two hypotheses the following regression is estimated using Hansen's (1982) generalized method of moments (GMM) technique:

$$Depth\ Quantity_t = \alpha_0 + \beta_1 Volatility_{t-1} + \varepsilon_t \quad (4.5)$$

$$Depth\ Frequency_t = \alpha_0 + \beta_1 Volatility_{t-1} + \varepsilon_t \quad (4.6)$$

The computed t-statistics are adjusted for heteroskedasticity and autocorrelation using the Newey and West (1987) procedure. A positive (negative) and statistically significant coefficient on volatility implies a positive (negative) relation between volatility and depth. Each of these hypotheses is tested separately for the day and night trading sessions using both the five- and fifteen-minute time intervals.

Ahn, Bae, and Chan (2001) argue for the inclusion of several control variables including frequency of trades, intraday time dummy variables, and lagged depth. The frequency is included as a control because the realized volatility measure is positively correlated with the number of trades in an interval. Furthermore, the time dummies and lagged depth are included to control for the intraday variation and autocorrelation in market depth. The expanded models with the control variables are shown as follows:

$$\begin{aligned} \text{Depth Frequency}_t = & \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \beta_2 \text{Frequency}_t + \beta_3 \text{Depth}_{t-1} + \sum_{i=1}^6 \phi_i D_i \\ & + \sum_{i=T-5}^T \phi_i D_i + \varepsilon_t \end{aligned} \quad (4.7)$$

$$\begin{aligned} \text{Depth Frequency}_t = & \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \beta_2 \text{Frequency}_t + \beta_3 \text{Depth}_{t-1} + \sum_{i=1}^2 \phi_i D_i \\ & + \sum_{i=T-1}^T \phi_i D_i + \varepsilon_t \end{aligned} \quad (4.8)$$

$$\begin{aligned} \text{Depth Quantity}_t = & \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \beta_2 \text{Volume}_t + \beta_3 \text{Depth}_{t-1} + \sum_{i=1}^6 \phi_i D_i \\ & + \sum_{i=T-5}^T \phi_i D_i + \varepsilon_t \end{aligned} \quad (4.9)$$

$$\begin{aligned} \text{Depth Quantity}_t = & \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \beta_2 \text{Volume}_t + \beta_3 \text{Depth}_{t-1} + \sum_{i=1}^2 \phi_i D_i \\ & + \sum_{i=T-1}^T \phi_i D_i + \varepsilon_t \end{aligned} \quad (4.10)$$

where Volatility_{t-1} denotes the transitory volatility, Frequency_t is calculated as the number of trades in an interval, Volume_t is calculated as the sum of traded volume in an interval, Depth_{t-1} represents the lagged depth, and the D_i variables are the dummy variables that take a value of one for the first and last half hours of trading and zero otherwise.

Equations 4.7 and 4.9 employ fifteen-minute intervals whereas equations 4.8 and 4.10 use five-minute intervals.

4.5. Results

4.5.1. Summary Statistics

The summary statistics for the three volatility measures using five-minute intervals for the day period are provided in Table 4.1. Panels A, B, C, D, E, and F provide a summary of the GK volatility, returns volatility, and realized volatility for the six futures contracts. The contract with the smallest average GK volatility (0.30), returns volatility (0.38), and realized volatility (1.37) is the T-note futures in Panel A, whereas the contract with the largest mean GK volatility (21.15), returns volatility (2.42), and realized volatility (171.66) is oil futures in Panel C. The median values of the three volatility measures for the euro and yen futures in Panels D and E are almost identical. Based on the moments presented in Table 4.1, the three volatility measures have different distributions across the contracts.

Table 4.2 describes the summary statistics for the day time volatility measures over the fifteen-minute time intervals. There is an increase in the mean for all three of the volatility measures for the fifteen-minute intervals across the contracts relative to the five-minute values. Thus, the fifteen-minute intervals not only have more trades than the five-minute intervals, but they also possess a greater dispersion among the trade prices, resulting in higher average volatility measures.

Table 4.3 presents the summary statistics for the volatility measures during night trading using five-minute intervals. Similar to Table 4.1, the T-note contract has the lowest mean volatility measures whereas oil has the largest. In comparing the day and

night periods using five-minute intervals, the average volatility using all three measures is smaller for the night than for the day periods. For example, using Table 4.3 (Table 4.1) the night (day) corn futures mean GK volatility is 0.97 (0.9.38), returns volatility of 0.86 (2.06), and realized volatility of 8.50 (38.52) for the five-minute time interval.

The summary statistics of the volatility measures for the fifteen-minute time interval during the night are described in Table 4.4. Across every contract and measure, the volatility is larger compared to the five-minute night session. To summarize, the volatility measures are smaller for the five-minute intervals relative to the fifteen-minute intervals and the measures are larger during the day compared to the night.

4.5.2. Depth and Volatility

The next set of tables presents the results for the relation between depth and transitory volatility during the day using the base regressions for depth quantity. The regressions examine depth quantity using five-minute intervals (4.5), depth frequency using five-minute intervals (4.6), depth quantity using fifteen-minute intervals (4.7), and depth frequency using fifteen-minute intervals (4.8). The overall results from these tables strongly support an inverse relation between transitory volatility and depth using all three volatility measures for all contracts. For example, in Panel A of Table 4.5 (T-notes), a negative and statistically significant coefficient occurs on each of the three transitory volatility measures. The main implication is that a decrease in volatility in one period leads to an increase in depth in the following period.

On the other hand, the results for the relation between lagged volatility and depth during the night trading in Tables 4.9 (five-minute intervals for depth quantity), 4.10 (five-minute intervals for depth frequency), 4.11 (fifteen-minute intervals for depth

quantity), and 4.12 (fifteen-minute intervals for depth frequency) are not as straightforward. In Table 4.9, the euro and yen futures show evidence of a negative relation between transitory volatility and depth, whereas the T-note and oil futures support a positive relation. The results for gold futures in Panel F are not consistent because the coefficient on the GK volatility is not significant, on the return volatility it is negative and significant, and on the realized volatility the coefficient is positive and significant. The results in Tables 4.10, 4.11, and 4.12 follow a similar pattern.

To summarize, the base regression results between depth and transitory volatility support an inverse relation during the day for all contracts using both five-minute and fifteen-minute intervals. However, the relation for night trading is more complex and dependent on the contract, time interval, depth definition, and volatility measure.

4.5.3. Depth and Volatility with Control Factors

The next set of results is for the expanded models that explore the relation between transitory volatility and depth, with the addition of control variables. Tables 4.13 through 4.16 present the results for the day session. In Table 4.13 examining depth quantity using five-minute intervals, four futures (corn, oil, euro, and gold) show a negative relation. For depth frequency using 5-minute intervals in Table 4.14, T-notes, euro, yen, and gold support a negative relation. In Table 4.15 corn, oil, euro, and gold futures for depth quantity using fifteen-minute intervals display an inverse relation. In Table 4.16, T-notes, euro, yen, and gold futures using depth frequency for fifteen-minute intervals show evidence of a negative relation between lagged volatility and depth. Overall, the relation between transitory volatility and depth after accounting for control

factors is generally negative during the day, although the results are sensitive to the depth measure employed.

The final set of tables explores the volatility-depth relation during the night period after accounting for control factors. The results for Tables 4.17, 4.18, 4.19, and 4.20 are very consistent and show evidence consistent with a negative relation between lagged volatility and depth, even after accounting for control factors. The presented evidence for the negative relation is consistent with Chen and Wu (2009), and Chiang, Lin, and Yu (2009) but in disagreement with Ahn, Bae, and Chan (2001), who find a positive relation.

4.6 Conclusion

In conclusion, this chapter examines the relation between transitory volatility and depth using a unique sample of U.S. futures market data with five levels of depth. Overall, the results support a negative relation between transitory volatility and depth. Contrary to prior studies which only examine the traditional trading period, this relation is established for the U.S. electronic futures market during both day and night trading after accounting for control factors.

Table 4.1 Summary Volatility Five-Minute Day

This table presents the summary statistics of the volatility measures for the five-minute time intervals during the day. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval.

	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel A: T-note							
GK Volatility	0.30	0.16	0.60	14.19	365.34	0.03	0.90
Returns Volatility	0.38	0.27	0.39	3.00	23.24	0.00	1.09
Realized Volatility	1.37	0.75	5.62	38.79	2270.67	0.24	2.94
Panel B: Corn							
GK Volatility	9.38	4.36	20.06	14.48	458.61	0.40	31.94
Returns Volatility	2.06	1.37	2.29	2.84	14.19	0.00	6.29
Realized Volatility	38.52	17.65	159.36	30.29	1434.95	3.63	100.35
Panel C: Oil							
GK Volatility	21.15	9.06	47.99	10.84	182.72	1.87	68.85
Returns Volatility	2.42	1.67	2.58	3.03	17.78	0.16	7.32
Realized Volatility	171.66	61.62	484.67	16.15	564.38	12.28	569.81
Panel D: Euro							
GK Volatility	6.39	0.28	25.36	8.09	91.95	0.03	40.09
Returns Volatility	0.49	0.32	0.78	11.13	221.31	0.00	1.42
Realized Volatility	60.86	0.70	370.09	20.54	705.75	0.13	285.67
Panel E: Yen							
GK Volatility	4.28	0.29	18.08	8.60	114.40	0.04	23.44
Returns Volatility	0.53	0.33	0.79	9.20	161.71	0.00	1.52
Realized Volatility	45.09	0.66	325.14	20.13	660.56	0.15	147.39
Panel F: Gold							
GK Volatility	5.04	1.74	16.94	9.92	133.17	0.31	13.69
Returns Volatility	1.26	0.89	1.36	4.30	47.82	0.11	3.63
Realized Volatility	28.34	3.60	181.56	10.06	118.04	0.98	27.38

Table 4.2 Summary Volatility Fifteen-Minute Day

This table presents the summary statistics of the volatility measures for the fifteen-minute time intervals during the day. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval.

	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel A: T-note							
GK Volatility	0.92	0.55	1.47	9.74	176.84	0.12	2.84
Returns Volatility	0.67	0.53	0.64	2.24	8.69	0.00	1.87
Realized Volatility	3.74	2.31	9.63	25.06	918.44	0.85	9.05
Panel B: Corn							
GK Volatility	28.90	14.35	49.44	6.87	85.48	1.74	101.10
Returns Volatility	3.54	2.50	3.66	2.31	8.24	0.00	10.68
Realized Volatility	115.32	55.49	295.95	15.61	398.26	13.14	367.04
Panel C: Oil							
GK Volatility	53.32	24.57	92.83	7.31	92.67	5.45	173.09
Returns Volatility	4.21	2.90	4.43	2.83	13.98	0.24	12.28
Realized Volatility	461.92	198.31	856.63	9.09	186.08	49.69	1551.67
Panel D: Euro							
GK Volatility	12.14	1.15	34.62	6.04	51.56	0.11	65.51
Returns Volatility	0.82	0.55	0.99	4.75	41.41	0.06	2.36
Realized Volatility	174.58	2.77	909.26	16.96	457.35	0.45	777.88
Panel E: Yen							
GK Volatility	8.34	1.04	25.82	7.09	74.64	0.15	45.74
Returns Volatility	0.87	0.57	1.10	6.04	82.31	0.09	2.57
Realized Volatility	131.68	2.25	797.15	13.19	224.82	0.58	486.52
Panel F: Gold							
GK Volatility	12.44	5.64	27.64	8.94	128.90	1.07	39.96
Returns Volatility	2.16	1.56	2.32	3.89	31.29	0.11	6.13
Realized Volatility	45.90	11.36	195.72	9.10	102.65	3.32	94.48

Table 4.3 Summary Volatility Five-Minute Night

This table presents the summary statistics of the volatility measures for the five-minute time intervals during the night. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval.

	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel A: T-note							
GK Volatility	0.07	0.03	0.24	25.47	1395.24	0.00	0.25
Returns Volatility	0.20	0.14	0.39	14.28	333.75	0.00	0.55
Realized Volatility	0.45	0.11	4.50	41.83	2498.21	0.00	0.70
Panel B: Corn							
GK Volatility	0.97	0.09	4.82	30.37	1525.59	0.00	3.93
Returns Volatility	0.86	0.63	1.06	3.85	37.63	0.00	2.73
Realized Volatility	8.50	1.00	126.48	43.95	2729.79	0.00	10.93
Panel C: Oil							
GK Volatility	4.87	0.62	35.48	40.13	2599.56	0.00	15.05
Returns Volatility	1.10	0.57	2.33	18.35	641.72	0.00	3.60
Realized Volatility	38.09	1.88	389.02	31.96	1700.67	0.05	65.86
Panel D: Euro							
GK Volatility	1.68	0.10	11.64	16.82	452.70	0.00	2.88
Returns Volatility	0.36	0.22	0.65	13.28	300.98	0.00	1.06
Realized Volatility	13.75	0.22	121.18	24.28	1196.69	0.02	12.90
Panel E: Yen							
GK Volatility	1.26	0.11	10.32	22.97	913.64	0.00	2.01
Returns Volatility	0.42	0.28	0.72	11.68	217.52	0.00	1.17
Realized Volatility	8.73	0.29	120.56	53.96	4523.44	0.04	5.20
Panel F: Gold							
GK Volatility	1.68	0.28	9.86	15.38	367.38	0.01	3.76
Returns Volatility	0.69	0.43	1.18	17.53	718.14	0.00	2.06
Realized Volatility	13.02	0.69	122.58	14.92	297.69	0.07	7.67

Table 4.4 Summary Volatility Fifteen-Minute Night

This table presents the summary statistics of the volatility measures for the fifteen-minute time intervals during the night. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval.

	Mean	Median	Std Dev	Skew	Kurt	5th	95th
Panel A: T-note							
GK Volatility	0.22	0.08	0.55	14.64	372.65	0.00	0.78
Returns Volatility	0.36	0.26	0.65	8.69	113.30	0.00	1.05
Realized Volatility	1.14	0.35	7.52	26.31	948.12	0.04	2.08
Panel B: Corn							
GK Volatility	3.34	0.80	11.83	16.19	417.87	0.00	12.40
Returns Volatility	1.32	0.84	1.64	4.38	48.05	0.00	4.19
Realized Volatility	23.45	3.25	211.44	25.94	955.65	0.24	34.26
Panel C: Oil							
GK Volatility	11.80	2.49	54.63	29.70	1426.28	0.08	42.34
Returns Volatility	1.99	0.99	3.82	10.75	214.40	0.08	6.53
Realized Volatility	77.63	7.13	573.56	27.36	1106.86	0.32	204.35
Panel D: Euro							
GK Volatility	3.43	0.39	16.59	13.25	277.96	0.03	13.45
Returns Volatility	0.63	0.39	0.98	8.58	136.99	0.00	1.86
Realized Volatility	32.62	0.78	241.58	19.65	606.24	0.11	94.30
Panel E: Yen							
GK Volatility	3.01	0.46	16.96	24.55	1186.51	0.05	9.04
Returns Volatility	0.72	0.45	1.07	7.47	94.44	0.00	2.06
Realized Volatility	24.46	0.97	300.62	58.45	5429.16	0.20	38.95
Panel F: Gold							
GK Volatility	3.82	1.11	14.50	13.62	284.03	0.11	11.42
Returns Volatility	1.22	0.75	2.08	12.93	346.72	0.10	3.58
Realized Volatility	18.62	2.28	137.35	15.91	392.08	0.39	23.16

Table 4.5 Depth Quantity and Transitory Volatility Five-Minute Day

This table presents the coefficient estimates for the following model:

$$Depth\ Quantity_t = \alpha_0 + \beta_1 Volatility_{t-1} + \varepsilon_t$$

Depth quantity is calculated as the sum of the depth available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-Note			
Intercept	8466.61 (97.49*)	8876.32 (103.86*)	8184.26 (78.97*)
GK Volatility	-1062.0 (-6.82*)		
Returns Volatility		-1908.4 (-17.09*)	
Realized Volatility			-29.507 (-2.94*)
Panel B: Corn			
Intercept	576.222 (101.92*)	597.510 (102.93*)	560.734 (91.56*)
GK Volatility	-1.811 (-6.26*)		
Returns Volatility		-18.370 (-16.58*)	
Realized Volatility			-0.049 (-2.22**)
Panel C: Oil			
Intercept	105.840 (121.09*)	109.055 (117.43*)	104.364 (98.57*)
GK Volatility	-0.122 (-6.24*)		
Returns Volatility		-2.394 (-15.54*)	
Realized Volatility			-0.006 (-5.46*)
Panel D: Euro			
Intercept	647.255 (156.84*)	672.967 (128.48*)	642.611 (117.35*)
GK Volatility	-1.097 (-15.16*)		
Returns Volatility		-66.237 (-9.09*)	
Realized Volatility			-0.039 (-6.09*)
Panel E: Yen			
Intercept	553.479 (117.83*)	578.730 (106.19*)	550.247 (88.24*)
GK Volatility	-0.829 (-5.95*)		
Returns Volatility		-54.025 (-10.00*)	
Realized Volatility			-0.007 (-0.60)
Panel F: Gold			
Intercept	106.116 (153.51*)	111.482 (142.79*)	105.305 (117.43*)
GK Volatility	-0.143 (-3.50*)		
Returns Volatility		-4.840 (-15.11*)	
Realized Volatility			0.003 (0.82)

Table 4.6 Depth Frequency and Transitory Volatility Five-Minute Day

This table presents the coefficient estimates for the following model:

$$\text{Depth Frequency}_t = \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \varepsilon_t$$

Depth frequency is calculated as the sum of the number of orders available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-Note			
Intercept	506.831 (139.26*)	522.133 (146.69*)	494.531 (114.32*)
GK Volatility	-49.307 (-7.64*)		
Returns Volatility		-78.912 (-16.93*)	
Realized Volatility			-1.959 (-3.95*)
Panel B: Corn			
Intercept	96.095 (119.24*)	98.390 (113.05*)	94.491 (95.77*)
GK Volatility	-0.162 (-6.17*)		
Returns Volatility		-1.831 (-10.97*)	
Realized Volatility			0.001 (0.62)
Panel C: Oil			
Intercept	57.918 (133.68*)	58.585 (124.05*)	57.312 (102.53*)
GK Volatility	-0.031 (-5.65*)		
Returns Volatility		-0.546 (-6.42*)	
Realized Volatility			0.000 (-0.49)
Panel D: Euro			
Intercept	190.013 (171.80*)	195.121 (155.02*)	188.738 (130.05*)
GK Volatility	-0.298 (-16.52*)		
Returns Volatility		-14.195 (-10.19*)	
Realized Volatility			-0.010 (-6.33*)
Panel E: Yen			
Intercept	160.040 (169.96*)	166.431 (149.45*)	159.172 (128.48*)
GK Volatility	-0.278 (-11.49*)		
Returns Volatility		-14.223 (-11.25*)	
Realized Volatility			-0.007 (-4.05*)
Panel F: Gold			
Intercept	50.697 (179.73*)	53.387 (169.30*)	50.222 (135.73*)
GK Volatility	-0.112 (-6.26*)		
Returns Volatility		-2.586 (-19.74*)	
Realized Volatility			-0.003 (-2.23**)

Table 4.7 Depth Quantity and Transitory Volatility Fifteen-Minute Day

This table presents the coefficient estimates for the following model:

$$Depth\ Quantity_t = \alpha_0 + \beta_1 Volatility_{t-1} + \varepsilon_t$$

Depth quantity is calculated as the sum of the depth available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-Note			
Intercept	8660.85 (56.70*)	8849.53 (62.70*)	8260.73 (47.00*)
GK Volatility	-552.13 (-5.45*)		
Returns Volatility		-1041.0 (-9.87*)	
Realized Volatility			-28.336 (-3.56*)
Panel B: Corn			
Intercept	578.489 (71.74*)	582.685 (66.87*)	560.905 (59.46*)
GK Volatility	-0.686 (-7.87*)		
Returns Volatility		-6.775 (-6.58*)	
Realized Volatility			-0.023 (-1.59)
Panel C: Oil			
Intercept	107.304 (71.83*)	108.662 (69.67*)	105.027 (55.36*)
GK Volatility	-0.079 (-6.66*)		
Returns Volatility		-1.321 (-9.15*)	
Realized Volatility			-0.004 (-4.03*)
Panel D: Euro			
Intercept	654.490 (92.50*)	694.424 (87.71*)	642.387 (69.68*)
GK Volatility	-1.248 (-12.73*)		
Returns Volatility		-67.363 (-13.00*)	
Realized Volatility			-0.017 (-4.56*)
Panel E: Yen			
Intercept	558.610 (68.82*)	586.525 (64.68*)	550.581 (51.76*)
GK Volatility	-1.009 (-6.34*)		
Returns Volatility		-41.822 (-8.72*)	
Realized Volatility			-0.003 (-0.34)
Panel F: Gold			
Intercept	107.892 (91.04*)	110.558 (90.04*)	105.596 (70.95*)
GK Volatility	-0.205 (-4.70*)		
Returns Volatility		-2.414 (-9.34*)	
Realized Volatility			-0.006 (-0.94)

Table 4.8 Depth Frequency and Transitory Volatility Fifteen-Minute Day

This table presents the coefficient estimates for the following model:

$$\text{Depth Frequency}_t = \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \varepsilon_t$$

Depth frequency is calculated as the sum of the number of orders available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-Note			
Intercept	513.532 (80.73*)	519.693 (87.67*)	496.513 (69.01*)
GK Volatility	-23.543 (-5.60*)		
Returns Volatility		-41.566 (-9.19*)	
Realized Volatility			-1.219 (-4.40*)
Panel B: Corn			
Intercept	95.553 (72.79*)	96.109 (66.61*)	93.356 (57.54*)
GK Volatility	-0.040 (-3.53*)		
Returns Volatility		-0.478 (-2.90*)	
Realized Volatility			0.009 (4.47*)
Panel C: Oil			
Intercept	58.086 (77.56*)	58.273 (73.06*)	56.634 (58.05*)
GK Volatility	-0.016 (-4.02*)		
Returns Volatility		-0.245 (-2.94*)	
Realized Volatility			0.001 (2.03**)
Panel D: Euro			
Intercept	191.701 (102.74*)	198.788 (100.87*)	188.454 (80.35*)
GK Volatility	-0.335 (-14.52*)		
Returns Volatility		-13.637 (-12.97*)	
Realized Volatility			-0.005 (-4.72*)
Panel E: Yen			
Intercept	161.065 (101.80*)	168.041 (95.41*)	159.092 (78.64*)
GK Volatility	-0.287 (-9.88*)		
Returns Volatility		-10.790 (-10.19*)	
Realized Volatility			-0.003 (-2.42**)
Panel F: Gold			
Intercept	51.527 (104.76*)	52.917 (106.43*)	50.376 (82.24*)
GK Volatility	-0.115 (-6.05*)		
Returns Volatility		-1.307 (-12.94*)	
Realized Volatility			-0.006 (-2.63*)

Table 4.9 Depth Quantity and Transitory Volatility Five-Minute Night

This table presents the coefficient estimates for the following model:

$$Depth\ Quantity_t = \alpha_0 + \beta_1 Volatility_{t-1} + \varepsilon_t$$

Depth quantity is calculated as the sum of the depth available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-Note			
Intercept	3930.33 (123.15*)	3915.89 (123.96*)	3922.49 (93.28*)
GK Volatility	81.433 (0.67)		
Returns Volatility		102.478 (1.83***)	
Realized Volatility			31.157 (2.81*)
Panel B: Corn			
Intercept	203.703 (102.30*)	212.706 (88.89*)	203.120 (80.23*)
GK Volatility	-0.441 (-1.73***)		
Returns Volatility		-11.027 (-10.91*)	
Realized Volatility			0.017 (3.16*)
Panel C: Oil			
Intercept	49.211 (188.42*)	48.452 (178.93*)	49.176 (147.69*)
GK Volatility	0.008 (1.45)		
Returns Volatility		0.722 (8.60*)	
Realized Volatility			0.002 (2.11**)
Panel D: Euro			
Intercept	379.177 (207.67*)	390.781 (194.09*)	378.695 (155.85*)
GK Volatility	-0.772 (-8.86*)		
Returns Volatility		-35.416 (-14.36*)	
Realized Volatility			-0.059 (-5.29*)
Panel E: Yen			
Intercept	356.537 (165.24*)	370.697 (155.42*)	355.681 (123.40*)
GK Volatility	-1.073 (-8.52*)		
Returns Volatility		-37.416 (-16.85*)	
Realized Volatility			-0.056 (-4.16*)
Panel F: Gold			
Intercept	70.810 (244.67*)	72.041 (218.94*)	70.696 (192.44*)
GK Volatility	-0.021 (-0.85)		
Returns Volatility		-1.843 (-7.85*)	
Realized Volatility			0.006 (2.97*)

Table 4.10 Depth Frequency and Transitory Volatility Five-Minute Night

This table presents the coefficient estimates for the following model:

$$\text{Depth Frequency}_t = \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \varepsilon_t$$

Depth frequency is calculated as the sum of the number of orders available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-Note			
Intercept	203.703 (143.70*)	200.402 (144.78*)	203.965 (110.31*)
GK Volatility	13.133 (2.29**)		
Returns Volatility		21.471 (8.22*)	
Realized Volatility			1.521 (3.20*)
Panel B: Corn			
Intercept	36.283 (118.18*)	37.960 (99.65*)	36.100 (91.35*)
GK Volatility	-0.167 (-5.32*)		
Returns Volatility		-2.152 (-15.16*)	
Realized Volatility			0.002 (3.20*)
Panel C: Oil			
Intercept	23.355 (217.02*)	22.576 (187.11*)	23.383 (167.34*)
GK Volatility	0.017 (3.48*)		
Returns Volatility		0.783 (11.58*)	
Realized Volatility			0.002 (3.64*)
Panel D: Euro			
Intercept	103.206 (184.88*)	104.645 (179.00*)	103.211 (139.05*)
GK Volatility	-0.040 (-1.45)		
Returns Volatility		-4.137 (-9.72*)	
Realized Volatility			-0.005 (-1.59)
Panel E: Yen			
Intercept	87.097 (183.87*)	89.277 (176.83*)	86.975 (138.27*)
GK Volatility	-0.177 (-8.96*)		
Returns Volatility		-5.793 (-14.53*)	
Realized Volatility			-0.011 (-5.09*)
Panel F: Gold			
Intercept	26.431 (324.43*)	26.578 (314.61*)	26.387 (247.11*)
GK Volatility	-0.030 (-4.75*)		
Returns Volatility		-0.288 (-5.62*)	
Realized Volatility			-0.001 (-1.04)

Table 4.11 Depth Quantity and Transitory Volatility Fifteen-Minute Night

This table presents the coefficient estimates for the following model:

$$Depth\ Quantity_t = \alpha_0 + \beta_1 Volatility_{t-1} + \varepsilon_t$$

Depth quantity is calculated as the sum of the depth available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-Note			
Intercept	3925.69 (74.40*)	3824.26 (74.07*)	3871.04 (57.59*)
GK Volatility	-162.72 (-2.30**)		
Returns Volatility		184.883 (3.36*)	
Realized Volatility			17.495 (2.17**)
Panel B: Corn			
Intercept	201.530 (66.49*)	208.818 (58.59*)	200.301 (54.23*)
GK Volatility	-0.204 (-1.59)		
Returns Volatility		-6.041 (-6.38*)	
Realized Volatility			0.023 (3.43*)
Panel C: Oil			
Intercept	48.976 (121.44*)	47.858 (116.48*)	48.944 (99.89*)
GK Volatility	0.014 (2.31**)		
Returns Volatility		0.646 (8.99*)	
Realized Volatility			0.003 (2.76*)
Panel D: Euro			
Intercept	379.193 (123.62*)	394.240 (118.98*)	377.095 (95.40*)
GK Volatility	-0.897 (-9.52*)		
Returns Volatility		-28.698 (-14.84*)	
Realized Volatility			-0.030 (-3.46*)
Panel E: Yen			
Intercept	356.688 (96.73*)	375.866 (92.33*)	354.357 (74.04*)
GK Volatility	-1.024 (-5.56*)		
Returns Volatility		-31.128 (-16.33*)	
Realized Volatility			-0.031 (-2.85*)
Panel F: Gold			
Intercept	70.832 (154.59*)	71.599 (149.15*)	70.339 (124.57*)
GK Volatility	-0.119 (-3.66*)		
Returns Volatility		-1.005 (-6.76*)	
Realized Volatility			0.002 (0.76)

Table 4.12 Depth Frequency and Transitory Volatility Fifteen-Minute Night

This table presents the coefficient estimates for the following model:

$$\text{Depth Frequency}_t = \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \varepsilon_t$$

Depth frequency is calculated as the sum of the number of orders available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-Note			
Intercept	201.776 (87.88*)	194.560 (87.25*)	200.636 (69.91*)
GK Volatility	0.893 (0.31)		
Returns Volatility		20.681 (8.07*)	
Realized Volatility			1.198 (2.90*)
Panel B: Corn			
Intercept	36.205 (73.30*)	37.690 (63.35*)	35.863 (58.68*)
GK Volatility	-0.082 (-4.71*)		
Returns Volatility		-1.332 (-9.33*)	
Realized Volatility			0.003 (2.97*)
Panel C: Oil			
Intercept	23.077 (129.40*)	22.090 (123.76*)	23.177 (110.89*)
GK Volatility	0.022 (3.35*)		
Returns Volatility		0.625 (12.00*)	
Realized Volatility			0.002 (3.69*)
Panel D: Euro			
Intercept	102.723 (110.42*)	104.349 (106.65*)	102.494 (86.89*)
GK Volatility	-0.074 (-2.49**)		
Returns Volatility		-2.977 (-7.59*)	
Realized Volatility			-0.001 (-0.29)
Panel E: Yen			
Intercept	86.722 (110.01*)	89.206 (105.51*)	86.342 (86.76*)
GK Volatility	-0.177 (-5.90*)		
Returns Volatility		-4.219 (-11.42*)	
Realized Volatility			-0.006 (-3.41*)
Panel F: Gold			
Intercept	26.358 (196.51*)	26.353 (196.29*)	26.190 (156.42*)
GK Volatility	-0.049 (-5.85*)		
Returns Volatility		-0.149 (-4.11*)	
Realized Volatility			-0.001 (-1.50)

Table 4.13 Depth Quantity, Transitory Volatility, and Controls Five-Minute Day

This table presents the coefficient estimates for the following model:

$$\text{Depth Quantity}_t = \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \beta_2 \text{Volume}_t + \beta_3 \text{Depth}_{t-1} + \sum_{i=1}^6 \phi_i D_i + \sum_{i=T-5}^T \phi_i D_i + \varepsilon_t$$

Depth quantity is calculated as the sum of the depth available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Volume is computed as the sum of trade volume in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-note			
Intercept	58.209 (4.00*)	50.357 (3.06*)	62.140 (4.51*)
GK Volatility	17.818 (0.97)		
Returns Volatility		33.491 (1.47)	
Realized Volatility			2.074 (1.51)
Volume	0.022 (11.59*)	0.022 (11.32*)	0.022 (12.03*)
Depth	0.969 (519.61*)	0.969 (509.50*)	0.968 (527.07*)
D ₁	-786.89 (-4.75*)	-787.09 (-4.75*)	-787.86 (-4.75*)
D ₂	-1017.7 (-10.17*)	-1019.6 (-10.18*)	-1048.0 (-9.94*)
D ₃	948.870 (9.98*)	954.299 (10.02*)	947.978 (9.99*)
D ₄	985.206 (12.16*)	992.898 (12.28*)	997.154 (12.29*)
D ₅	234.599 (4.68*)	234.436 (4.69*)	234.731 (4.69*)
D ₆	29.112 (0.58)	28.847 (0.57)	29.261 (0.58)
D _{T-5}	27.557 (0.59)	27.377 (0.59)	28.057 (0.60)
D _{T-4}	54.429 (1.18)	54.381 (1.17)	54.814 (1.19)
D _{T-3}	6.685 (0.16)	5.906 (0.14)	7.760 (0.19)
D _{T-2}	-26.587 (-0.51)	-27.860 (-0.53)	-26.581 (-0.51)
D _{T-1}	12.869 (0.25)	12.731 (0.25)	13.681 (0.27)
D _T	172.189 (3.23*)	172.731 (3.25*)	171.000 (3.21*)
Panel B: Corn			
Intercept	123.743 (29.48*)	128.864 (29.88*)	121.401 (28.09*)
GK Volatility	-0.234 (-3.74*)		
Returns Volatility		-3.765 (-5.57*)	
Realized Volatility			0.000 (0.03)
Volume	-0.008 (-5.86*)	-0.007 (-4.65*)	-0.009 (-6.65*)
Depth	0.796 (109.89*)	0.793 (109.74*)	0.798 (108.25*)
D ₁	-61.360 (-3.71*)	-66.754 (-4.04*)	-61.149 (-3.74*)
D ₂	81.863 (7.68*)	79.756 (7.77*)	71.813 (6.51*)
D ₃	47.268 (5.12*)	46.186 (5.00*)	44.480 (4.81*)
D ₄	23.392 (2.37**)	24.604 (2.50**)	21.505 (2.19**)
D ₅	12.022 (1.28)	12.539 (1.34)	11.037 (1.18)
D ₆	23.216 (2.38**)	24.234 (2.50**)	22.503 (2.30**)
D _{T-5}	10.583 (1.31)	10.983 (1.36)	10.666 (1.33)
D _{T-4}	5.791 (0.72)	5.946 (0.74)	5.897 (0.73)
D _{T-3}	-2.970 (-0.32)	-2.655 (-0.28)	-2.973 (-0.32)
D _{T-2}	-0.476 (-0.05)	-0.285 (-0.03)	-0.704 (-0.07)
D _{T-1}	36.961 (3.75*)	37.032 (3.77*)	36.857 (3.74*)
D _T	58.991 (5.35*)	56.632 (5.11*)	60.340 (5.49*)

Table 4.13 (Continued)

Panel C: Oil			
Intercept	6.150 (18.71*)	6.740 (20.10*)	5.804 (16.51*)
GK Volatility	-0.015 (-5.37*)		
Returns Volatility		-0.409 (-8.57*)	
Realized Volatility			-0.001 (-2.93*)
Volume	0.001 (13.89*)	0.001 (14.63*)	0.001 (13.18*)
Depth	0.913 (318.68*)	0.911 (319.94*)	0.915 (288.12*)
D ₁	-15.794 (-10.71*)	-15.348 (-10.39*)	-16.116 (-11.03*)
D ₂	2.033 (2.18**)	2.167 (2.35**)	2.470 (2.59*)
D ₃	-0.301 (-0.33)	-0.282 (-0.31)	-0.319 (-0.35)
D ₄	0.586 (0.64)	0.663 (0.72)	0.580 (0.63)
D ₅	0.637 (0.75)	0.607 (0.72)	0.648 (0.76)
D ₆	-1.381 (-1.48)	-1.336 (-1.44)	-1.376 (-1.48)
D _{T-5}	-1.393 (-1.45)	-1.450 (-1.50)	-1.380 (-1.43)
D _{T-4}	-0.363 (-0.44)	-0.274 (-0.33)	-0.403 (-0.49)
D _{T-3}	-1.874 (-2.03**)	-1.878 (-2.04**)	-1.883 (-2.03**)
D _{T-2}	0.156 (0.15)	0.101 (0.10)	0.129 (0.12)
D _{T-1}	-0.886 (-0.93)	-0.951 (-1.00)	-0.934 (-0.98)
D _T	9.240 (7.38*)	8.675 (6.95*)	9.305 (7.29*)
Panel D: Euro			
Intercept	10.514 (15.06*)	11.200 (13.20*)	10.344 (15.11*)
GK Volatility	-0.016 (-1.39)		
Returns Volatility		-1.316 (-1.74***)	
Realized Volatility			0.000 (0.03)
Volume	0.001 (4.19*)	0.001 (4.43*)	0.001 (4.17*)
Depth	0.978 (987.76*)	0.977 (912.76*)	0.978 (1034.73*)
D ₁	101.725 (13.36*)	101.658 (13.36*)	101.728 (13.35*)
D ₂	-115.32 (-17.11*)	-115.00 (-17.02*)	-115.31 (-17.10*)
D ₃	14.497 (4.00*)	14.160 (3.91*)	14.556 (4.02*)
D ₄	90.950 (17.69*)	91.107 (17.70*)	90.973 (17.74*)
D ₅	22.985 (7.81*)	23.100 (7.86*)	22.992 (7.82*)
D ₆	11.870 (4.39*)	11.962 (4.43*)	11.883 (4.40*)
D _{T-5}	2.144 (0.77)	2.093 (0.75)	2.149 (0.77)
D _{T-4}	4.676 (1.86***)	4.665 (1.85***)	4.700 (1.86***)
D _{T-3}	1.647 (0.67)	1.688 (0.69)	1.650 (0.67)
D _{T-2}	-5.003 (-1.77***)	-5.123 (-1.81***)	-4.991 (-1.77***)
D _{T-1}	-5.605 (-2.32**)	-5.588 (-2.31**)	-5.589 (-2.32**)
D _T	6.669 (2.67*)	6.750 (2.70*)	6.683 (2.68*)

Table 4.13 (Continued)

Panel E: Yen			
Intercept	4.194 (8.94*)	3.559 (7.13*)	4.172 (9.59*)
GK Volatility	-0.009 (-0.60)		
Returns Volatility		1.069 (2.43**)	
Realized Volatility			-0.001 (-0.48)
Volume	0.001 (2.50**)	0.001 (1.94***)	0.001 (2.57**)
Depth	0.988 (1230.67*)	0.988 (1219.65*)	0.988 (1343.15*)
D ₁	62.290 (9.42*)	62.423 (9.44*)	62.302 (9.42*)
D ₂	-91.939 (-15.02*)	-92.029 (-15.04*)	-91.913 (-15.00*)
D ₃	9.826 (2.81*)	10.138 (2.91*)	9.826 (2.81*)
D ₄	81.344 (16.99*)	80.858 (16.97*)	81.363 (17.03*)
D ₅	27.720 (11.36*)	27.708 (11.36*)	27.714 (11.38*)
D ₆	7.316 (3.24*)	7.275 (3.22*)	7.303 (3.23*)
D _{T-5}	0.763 (0.40)	0.806 (0.42)	0.777 (0.40)
D _{T-4}	4.313 (2.47**)	4.298 (2.46**)	4.315 (2.47**)
D _{T-3}	4.886 (2.32**)	4.861 (2.30**)	4.867 (2.30**)
D _{T-2}	-8.826 (-3.75*)	-8.847 (-3.76*)	-8.824 (-3.76*)
D _{T-1}	-0.667 (-0.34)	-0.675 (-0.34)	-0.668 (-0.34)
D _T	6.394 (3.07*)	6.552 (3.14*)	6.390 (3.08*)
Panel F: Gold			
Intercept	13.962 (33.93*)	15.849 (36.10*)	13.740 (30.20*)
GK Volatility	-0.042 (-3.85*)		
Returns Volatility		-1.510 (-12.82*)	
Realized Volatility			0.000 (-0.04)
Volume	0.001 (14.25*)	0.002 (16.84*)	0.001 (12.68*)
Depth	0.843 (229.57*)	0.834 (222.77*)	0.845 (215.71*)
D ₁	-12.501 (-6.77*)	-12.810 (-6.95*)	-12.418 (-6.71*)
D ₂	-12.800 (-10.39*)	-11.719 (-9.39*)	-12.881 (-10.34*)
D ₃	-3.087 (-2.59*)	-3.728 (-3.13*)	-2.988 (-2.52**)
D ₄	5.122 (4.03*)	5.230 (4.14*)	5.065 (3.98*)
D ₅	-1.363 (-1.28)	-1.053 (-1.00)	-1.387 (-1.30)
D ₆	0.290 (0.23)	0.497 (0.40)	0.256 (0.20)
D _{T-5}	-2.887 (-2.16**)	-2.888 (-2.18**)	-2.888 (-2.16**)
D _{T-4}	2.512 (1.98**)	2.546 (2.01**)	2.479 (1.96***)
D _{T-3}	1.783 (1.31)	1.606 (1.18)	1.797 (1.32)
D _{T-2}	1.136 (0.81)	1.034 (0.74)	1.155 (0.82)
D _{T-1}	3.078 (2.18**)	3.010 (2.14**)	3.080 (2.18**)
D _T	12.819 (9.67*)	12.287 (9.27*)	12.928 (9.78*)

Table 4.14 Depth Frequency, Transitory Volatility, and Controls at Five-Minute Day

This table presents the coefficient estimates for the following model:

$$\text{Depth Frequency}_t = \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \beta_2 \text{Frequency}_t + \beta_3 \text{Depth}_{t-1} + \sum_{i=1}^6 \phi_i D_i + \sum_{i=T-5}^T \phi_i D_i + \varepsilon_t$$

Depth frequency is calculated as the sum of the number of orders available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Frequency is computed as the quantity of trades in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-note			
Intercept	194.319 (49.79*)	196.173 (48.82*)	192.768 (38.82*)
GK Volatility	-13.813 (-7.32*)		
Returns Volatility		-12.852 (-6.41*)	
Realized Volatility			-0.439 (-1.99**)
Frequency	0.034 (7.57*)	0.030 (6.98*)	0.026 (4.96*)
Depth	0.035 (89.51*)	0.036 (89.16*)	0.036 (68.81*)
D ₁	-91.453 (-11.00*)	-91.271 (-11.00*)	-91.172 (-10.84*)
D ₂	-115.53 (-14.48*)	-115.60 (-14.48*)	-110.49 (-12.69*)
D ₃	-22.274 (-3.59*)	-23.073 (-3.67*)	-20.319 (-3.08*)
D ₄	30.145 (4.93*)	20.008 (3.41*)	17.079 (2.84*)
D ₅	-1.128 (-0.20)	-1.329 (-0.24)	-1.662 (-0.30)
D ₆	-0.876 (-0.16)	-0.990 (-0.18)	-1.284 (-0.23)
D _{T-5}	-18.824 (-3.41*)	-18.908 (-3.43*)	-19.149 (-3.45*)
D _{T-4}	-16.177 (-2.97*)	-16.195 (-2.96*)	-16.306 (-2.97*)
D _{T-3}	-13.389 (-2.38**)	-13.525 (-2.39**)	-14.272 (-2.51**)
D _{T-2}	-16.472 (-2.78*)	-15.847 (-2.67*)	-16.289 (-2.73*)
D _{T-1}	-14.903 (-2.49**)	-15.132 (-2.54**)	-15.504 (-2.57**)
D _T	-20.756 (-3.55*)	-20.079 (-3.43*)	-19.260 (-3.26*)
Panel B: Corn			
Intercept	55.972 (39.59*)	57.011 (39.86*)	55.674 (32.82*)
GK Volatility	-0.021 (-1.58)		
Returns Volatility		-0.664 (-5.15*)	
Realized Volatility			0.009 (3.37*)
Frequency	0.002 (1.66***)	0.002 (2.44**)	0.001 (0.99)
Depth	0.071 (28.71*)	0.070 (28.60*)	0.071 (23.42*)
D ₁	-27.547 (-10.31*)	-28.076 (-10.57*)	-27.696 (-9.72*)
D ₂	-0.819 (-0.39)	-0.205 (-0.10)	-6.292 (-2.71*)
D ₃	3.223 (1.57)	3.361 (1.66***)	2.670 (1.32)
D ₄	3.578 (1.75***)	4.014 (1.97**)	3.233 (1.61)
D ₅	5.056 (2.53**)	5.277 (2.66*)	4.851 (2.47**)
D ₆	6.080 (3.06*)	6.354 (3.22*)	5.929 (3.06*)
D _{T-5}	-4.064 (-2.32**)	-3.996 (-2.29**)	-4.050 (-2.33**)
D _{T-4}	-6.435 (-3.61*)	-6.408 (-3.60*)	-6.422 (-3.61*)
D _{T-3}	-8.137 (-4.32*)	-8.075 (-4.29*)	-8.120 (-4.31*)
D _{T-2}	-9.524 (-4.91*)	-9.474 (-4.89*)	-9.545 (-4.92*)
D _{T-1}	-8.637 (-4.79*)	-8.608 (-4.77*)	-8.656 (-4.76*)
D _T	-24.147 (-14.40*)	-24.487 (-14.63*)	-23.890 (-13.46*)

Table 4.14 (Continued)

Panel C: Oil			
Intercept	11.806 (26.33*)	11.048 (25.48*)	12.042 (22.73*)
GK Volatility	0.029 (4.51*)		
Returns Volatility		0.733 (14.73*)	
Realized Volatility			0.003 (4.08*)
Frequency	0.000 (-6.02*)	-0.001 (-8.66*)	0.000 (-5.25*)
Depth	0.451 (120.04*)	0.452 (122.98*)	0.449 (96.06*)
D ₁	-7.980 (-9.21*)	-8.586 (-10.30*)	-8.703 (-9.16*)
D ₂	2.964 (4.60*)	2.763 (4.22*)	0.255 (0.31)
D ₃	2.396 (3.62*)	2.402 (3.65*)	2.441 (3.70*)
D ₄	2.868 (4.36*)	2.758 (4.18*)	2.864 (4.37*)
D ₅	2.423 (3.88*)	2.500 (4.02*)	2.421 (3.88*)
D ₆	1.568 (2.44**)	1.503 (2.34**)	1.580 (2.46**)
D _{T-5}	-4.325 (-7.10*)	-4.232 (-7.05*)	-4.353 (-7.15*)
D _{T-4}	-4.074 (-6.55*)	-4.225 (-6.84*)	-4.054 (-6.52*)
D _{T-3}	-5.253 (-9.85*)	-5.237 (-9.73*)	-5.327 (-9.86*)
D _{T-2}	-5.116 (-8.59*)	-5.000 (-8.21*)	-5.177 (-8.62*)
D _{T-1}	-5.245 (-8.32*)	-5.084 (-8.11*)	-5.358 (-8.44*)
D _T	-1.703 (-2.32**)	-0.849 (-1.15)	-1.983 (-2.55**)
Panel D: Euro			
Intercept	41.306 (25.53*)	45.133 (26.68*)	40.337 (20.38*)
GK Volatility	-0.138 (-11.36*)		
Returns Volatility		-8.313 (-9.06*)	
Realized Volatility			-0.006 (-5.88*)
Frequency	0.018 (22.99*)	0.019 (24.30*)	0.018 (20.31*)
Depth	0.189 (90.62*)	0.186 (89.73*)	0.190 (69.85*)
D ₁	36.446 (10.47*)	36.123 (10.33*)	36.865 (10.56*)
D ₂	-15.665 (-4.61*)	-13.617 (-3.93*)	-15.210 (-4.49*)
D ₃	-18.945 (-5.17*)	-20.401 (-5.50*)	-18.670 (-5.08*)
D ₄	17.219 (5.07*)	18.708 (5.58*)	17.596 (5.22*)
D ₅	13.220 (4.18*)	14.232 (4.57*)	13.291 (4.25*)
D ₆	13.903 (4.37*)	14.688 (4.67*)	13.945 (4.43*)
D _{T-5}	-10.357 (-4.80*)	-10.750 (-5.11*)	-10.370 (-4.79*)
D _{T-4}	-8.033 (-3.83*)	-8.124 (-3.91*)	-7.912 (-3.76*)
D _{T-3}	-7.840 (-3.86*)	-7.650 (-3.82*)	-7.872 (-3.87*)
D _{T-2}	-10.321 (-5.05*)	-11.119 (-5.44*)	-10.234 (-4.97*)
D _{T-1}	-9.724 (-4.84*)	-9.649 (-4.82*)	-9.560 (-4.75*)
D _T	-14.349 (-7.04*)	-13.791 (-6.55*)	-14.289 (-6.98*)

Table 4.14 (Continued)

Panel E: Yen			
Intercept	64.842 (53.90*)	68.394 (55.00*)	64.372 (42.66*)
GK Volatility	-0.194 (-11.58*)		
Returns Volatility		-8.760 (-10.40*)	
Realized Volatility			-0.008 (-7.52*)
Frequency	0.014 (14.64*)	0.016 (16.31*)	0.014 (12.31*)
Depth	0.156 (102.85*)	0.154 (102.34*)	0.156 (79.17*)
D ₁	18.248 (6.68*)	17.061 (6.26*)	18.326 (6.65*)
D ₂	-18.215 (-6.85*)	-17.626 (-6.57*)	-17.868 (-6.68*)
D ₃	-15.265 (-5.66*)	-16.825 (-6.07*)	-15.112 (-5.49*)
D ₄	16.505 (6.68*)	20.327 (8.25*)	16.652 (6.67*)
D ₅	13.776 (5.78*)	14.148 (6.02*)	13.714 (5.73*)
D ₆	12.901 (5.63*)	13.026 (5.74*)	12.644 (5.52*)
D _{T-5}	-14.069 (-7.81*)	-14.557 (-7.99*)	-13.919 (-7.60*)
D _{T-4}	-12.611 (-6.87*)	-12.743 (-7.11*)	-12.669 (-6.86*)
D _{T-3}	-11.978 (-6.48*)	-12.621 (-6.97*)	-12.502 (-6.74*)
D _{T-2}	-14.678 (-7.84*)	-14.661 (-7.87*)	-14.716 (-7.81*)
D _{T-1}	-13.678 (-7.57*)	-13.680 (-7.66*)	-13.731 (-7.51*)
D _T	-18.011 (-9.98*)	-19.157 (-10.79*)	-18.106 (-9.84*)
Panel F: Gold			
Intercept	19.693 (58.74*)	20.480 (60.99*)	19.482 (47.03*)
GK Volatility	-0.058 (-7.22*)		
Returns Volatility		-0.906 (-16.33*)	
Realized Volatility			-0.003 (-4.40*)
Frequency	-0.001 (-7.99*)	-0.001 (-4.61*)	-0.001 (-7.91*)
Depth	0.309 (101.52*)	0.306 (100.23*)	0.311 (82.62*)
D ₁	-12.106 (-18.53*)	-12.225 (-18.79*)	-12.035 (-18.16*)
D ₂	-10.736 (-19.54*)	-10.132 (-17.92*)	-10.316 (-17.75*)
D ₃	-5.433 (-11.28*)	-5.776 (-12.13*)	-5.337 (-10.95*)
D ₄	-0.691 (-1.34)	-0.687 (-1.33)	-0.786 (-1.50)
D ₅	-2.559 (-5.66*)	-2.408 (-5.33*)	-2.611 (-5.65*)
D ₆	-1.940 (-4.20*)	-1.851 (-4.07*)	-1.992 (-4.26*)
D _{T-5}	-2.351 (-4.64*)	-2.325 (-4.67*)	-2.349 (-4.63*)
D _{T-4}	-0.801 (-1.51)	-0.768 (-1.45)	-0.846 (-1.59)
D _{T-3}	-1.629 (-2.93*)	-1.682 (-3.04*)	-1.620 (-2.92*)
D _{T-2}	-2.199 (-3.75*)	-2.206 (-3.78*)	-2.187 (-3.71*)
D _{T-1}	-2.606 (-4.56*)	-2.613 (-4.59*)	-2.610 (-4.56*)
D _T	-3.427 (-6.13*)	-3.565 (-6.39*)	-3.347 (-5.94*)

Table 4.15 Depth Quantity, Transitory Volatility, and Controls Fifteen-Minute Day

This table presents the coefficient estimates for the following model:

$$\text{Depth Quantity}_t = \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \beta_2 \text{Volume}_t + \beta_3 \text{Depth}_{t-1} + \sum_{i=1}^2 \phi_i D_i + \sum_{i=T-1}^T \phi_i D_i + \varepsilon_t$$

Depth quantity is calculated as the sum of the depth available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Volume is computed as the sum of trade volume in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-note			
Intercept	125.541 (4.04*)	118.704 (3.74*)	154.607 (5.07*)
GK Volatility	21.438 (1.21)		
Returns Volatility		43.550 (1.46)	
Realized Volatility			-2.426 (-0.81)
Volume	0.007 (4.84*)	0.007 (5.06*)	0.008 (6.10*)
Depth	0.957 (259.89*)	0.957 (282.52*)	0.954 (292.32*)
D ₁	-928.99 (-5.60*)	-930.96 (-5.60*)	-948.92 (-5.65*)
D ₂	1660.58 (14.74*)	1677.75 (14.65*)	1731.00 (14.24*)
D _{T-1}	18.296 (0.34)	19.934 (0.37)	19.089 (0.35)
D _T	114.132 (1.98**)	113.509 (1.96**)	116.264 (2.02**)
Panel B: Corn			
Intercept	166.565 (19.59*)	167.816 (19.90*)	163.062 (18.17*)
GK Volatility	-0.127 (-3.10*)		
Returns Volatility		-1.867 (-2.67*)	
Realized Volatility			-0.008 (-0.78)
Volume	-0.003 (-2.95*)	-0.002 (-2.53**)	-0.003 (-3.33*)
Depth	0.720 (52.20*)	0.721 (53.16*)	0.724 (49.57*)
D ₁	-6.455 (-0.42)	-8.978 (-0.58)	-5.120 (-0.33)
D ₂	59.810 (5.67*)	56.363 (5.56*)	55.846 (5.05*)
D _{T-1}	5.934 (0.66)	5.959 (0.67)	5.853 (0.66)
D _T	40.365 (3.45*)	39.761 (3.36*)	41.436 (3.58*)
Panel C: Oil			
Intercept	2.967 (5.99*)	3.191 (6.29*)	2.297 (4.56*)
GK Volatility	-0.009 (-4.89*)		
Returns Volatility		-0.210 (-5.18*)	
Realized Volatility			0.000 (-0.02)
Volume	0.000 (10.70*)	0.000 (11.33*)	0.000 (10.29*)
Depth	0.934 (234.85*)	0.934 (237.83*)	0.938 (225.16*)
D ₁	-0.870 (-0.72)	-0.930 (-0.78)	-1.455 (-1.20)
D ₂	1.313 (1.77***)	1.381 (1.86***)	1.279 (1.71***)
D _{T-1}	-1.789 (-2.10**)	-1.936 (-2.27**)	-1.748 (-2.04**)
D _T	3.596 (3.77*)	3.342 (3.50*)	3.651 (3.83*)

Table 4.15 (Continued)

Panel D: Euro			
Intercept	14.560 (9.06*)	16.851 (9.82*)	13.215 (8.54*)
GK Volatility	-0.068 (-4.42*)		
Returns Volatility		-3.609 (-5.15*)	
Realized Volatility			0.000 (-0.45)
Volume	0.000 (1.85***)	0.000 (2.84*)	0.000 (1.68***)
Depth	0.968 (478.01*)	0.966 (464.04*)	0.970 (522.28*)
D ₁	33.626 (3.89*)	32.122 (3.73*)	33.950 (3.91*)
D ₂	84.826 (17.38*)	85.660 (17.58*)	85.080 (17.54*)
D _{T-1}	5.507 (1.91***)	5.873 (2.03**)	5.622 (1.94***)
D _T	-3.459 (-1.24)	-2.987 (-1.07)	-3.387 (-1.22)
Panel E: Yen			
Intercept	3.993 (4.05*)	4.038 (4.00*)	3.951 (4.27*)
GK Volatility	-0.006 (-0.31)		
Returns Volatility		-0.112 (-0.22)	
Realized Volatility			0.000 (-0.12)
Volume	0.001 (2.39**)	0.001 (2.30**)	0.001 (2.46**)
Depth	0.982 (606.32*)	0.982 (593.94*)	0.982 (645.30*)
D ₁	8.041 (1.12)	7.996 (1.12)	8.051 (1.12)
D ₂	78.432 (16.16*)	78.454 (16.16*)	78.441 (16.27*)
D _{T-1}	5.008 (2.17**)	5.000 (2.16**)	5.001 (2.16**)
D _T	0.100 (0.04)	0.083 (0.04)	0.084 (0.04)
Panel F: Gold			
Intercept	11.404 (17.88*)	12.247 (19.25*)	10.518 (15.65*)
GK Volatility	-0.057 (-5.32*)		
Returns Volatility		-0.813 (-8.46*)	
Realized Volatility			-0.003 (-1.98**)
Volume	0.001 (10.01*)	0.001 (10.48*)	0.000 (8.80*)
Depth	0.864 (155.90*)	0.861 (158.76*)	0.871 (151.84*)
D ₁	-15.398 (-9.58*)	-15.669 (-9.78*)	-14.961 (-9.25*)
D ₂	2.741 (2.67*)	3.271 (3.15*)	3.059 (2.91*)
D _{T-1}	1.867 (1.68***)	1.907 (1.72***)	1.873 (1.68***)
D _T	11.340 (8.41*)	11.302 (8.38*)	11.422 (8.46*)

Table 4.16 Depth Frequency, Transitory Volatility, and Controls Fifteen-Minute Day

This table presents the coefficient estimates for the following model:

$$\text{Depth Frequency}_t = \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \beta_2 \text{Frequency}_t + \beta_3 \text{Depth}_{t-1} + \sum_{i=1}^6 \phi_i D_i + \sum_{i=T-5}^T \phi_i D_i + \varepsilon_t$$

Depth frequency is calculated as the sum of the number of orders available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Frequency is computed as the quantity of trades in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-note			
Intercept	196.999 (29.24*)	197.716 (28.85*)	195.446 (24.18*)
GK Volatility	-5.801 (-3.44*)		
Returns Volatility		-7.210 (-3.28*)	
Realized Volatility			-0.393 (-2.58*)
Frequency	0.014 (4.44*)	0.012 (4.05*)	0.010 (3.29*)
Depth	0.035 (51.38*)	0.035 (52.15*)	0.035 (40.64*)
D ₁	-104.57 (-11.16*)	-102.47 (-10.88*)	-100.93 (-10.94*)
D ₂	57.864 (8.77*)	51.997 (7.91*)	57.052 (8.34*)
D _{T-1}	-14.945 (-2.77*)	-15.499 (-2.84*)	-15.666 (-3.11*)
D _T	-14.121 (-2.35**)	-14.579 (-2.42**)	-15.233 (-2.71*)
Panel B: Corn			
Intercept	54.299 (22.15*)	54.965 (22.41*)	53.759 (19.43*)
GK Volatility	-0.003 (-0.30)		
Returns Volatility		-0.285 (-2.05**)	
Realized Volatility			0.010 (3.82*)
Frequency	0.001 (2.22**)	0.002 (2.59*)	0.001 (1.54)
Depth	0.072 (16.56*)	0.071 (16.61*)	0.072 (13.84*)
D ₁	-13.945 (-5.19*)	-14.282 (-5.33*)	-13.856 (-4.95*)
D ₂	6.938 (3.57*)	7.588 (4.00*)	1.120 (0.55)
D _{T-1}	-5.833 (-3.41*)	-5.823 (-3.41*)	-5.732 (-4.28*)
D _T	-14.854 (-8.09*)	-15.049 (-8.19*)	-14.488 (-8.95*)
Panel C: Oil			
Intercept	8.637 (11.40*)	8.656 (11.91*)	8.717 (10.29*)
GK Volatility	0.022 (4.35*)		
Returns Volatility		0.417 (9.16*)	
Realized Volatility			0.004 (5.01*)
Frequency	0.000 (-2.42**)	0.000 (-3.40*)	0.000 (-3.02*)
Depth	0.472 (73.69*)	0.469 (74.47*)	0.470 (61.48*)
D ₁	-0.296 (-0.35)	0.188 (0.24)	-2.397 (-2.41**)
D ₂	2.801 (4.58*)	2.703 (4.36*)	-0.333 (-0.48)
D _{T-1}	-4.610 (-8.00*)	-4.365 (-7.51*)	-4.734 (-8.91*)
D _T	-3.149 (-4.74*)	-2.834 (-4.29*)	-3.318 (-5.24*)

Table 4.16 (Continued)

Panel D: Euro			
Intercept	38.113 (14.95*)	45.084 (17.32*)	35.441 (11.77*)
GK Volatility	-0.150 (-9.76*)		
Returns Volatility		-10.066 (-11.19*)	
Realized Volatility			-0.002 (-3.77*)
Frequency	0.008 (18.96*)	0.008 (20.65*)	0.008 (17.55*)
Depth	0.183 (56.32*)	0.178 (55.80*)	0.185 (44.96*)
D ₁	4.992 (1.32)	1.239 (0.33)	5.528 (1.50)
D ₂	19.415 (6.17*)	22.545 (7.03*)	19.912 (6.65*)
D _{T-1}	-4.591 (-2.23**)	-3.886 (-1.95***)	-4.311 (-2.19**)
D _T	-3.446 (-1.68***)	-2.489 (-1.21)	-3.170 (-1.61)
Panel E: Yen			
Intercept	62.078 (31.24*)	66.245 (32.84*)	61.121 (25.33*)
GK Volatility	-0.182 (-8.89*)		
Returns Volatility		-7.925 (-9.12*)	
Realized Volatility			-0.003 (-6.57*)
Frequency	0.007 (11.92*)	0.008 (13.17*)	0.006 (10.47*)
Depth	0.153 (62.63*)	0.151 (62.82*)	0.154 (49.95*)
D ₁	-4.376 (-1.57)	-7.626 (-2.70*)	-4.104 (-1.52)
D ₂	19.008 (7.77*)	21.001 (8.61*)	19.304 (8.32*)
D _{T-1}	-10.784 (-5.91*)	-10.867 (-6.04*)	-11.031 (-6.40*)
D _T	-11.326 (-6.29*)	-11.734 (-6.72*)	-11.886 (-7.01*)
Panel F: Gold			
Intercept	17.630 (33.04*)	17.807 (33.32*)	17.054 (26.89*)
GK Volatility	-0.051 (-6.92*)		
Returns Volatility		-0.506 (-11.96*)	
Realized Volatility			-0.004 (-4.11*)
Frequency	0.000 (-3.26*)	0.000 (-2.39**)	0.000 (-4.62*)
Depth	0.329 (70.08*)	0.330 (69.61*)	0.334 (57.77*)
D ₁	-11.852 (-18.07*)	-11.890 (-18.11*)	-11.496 (-17.24*)
D ₂	-1.017 (-2.26**)	-0.726 (-1.58)	-0.420 (-0.84)
D _{T-1}	-1.433 (-3.11*)	-1.389 (-3.00*)	-1.458 (-3.27*)
D _T	-2.393 (-4.80*)	-2.359 (-4.73*)	-2.387 (-4.92*)

Table 4.17 Depth Quantity, Transitory Volatility, and Controls Five-Minute Night

This table presents the coefficient estimates for the following model:

$$\text{Depth Quantity}_t = \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \beta_2 \text{Volume}_t + \beta_3 \text{Depth}_{t-1} + \sum_{i=1}^6 \phi_i D_i + \sum_{i=T-5}^T \phi_i D_i + \varepsilon_t$$

Depth quantity is calculated as the sum of the depth available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Volume is computed as the sum of trade volume in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-note			
Intercept	83.931 (18.99*)	89.649 (19.33*)	85.012 (20.37*)
GK Volatility	17.674 (1.07)		
Returns Volatility		-26.729 (-2.25**)	
Realized Volatility			-0.691 (-0.70)
Volume	0.012 (3.05*)	0.015 (3.55*)	0.013 (3.48*)
Depth	0.979 (660.77*)	0.978 (657.65*)	0.979 (692.29*)
D ₁	-2293.0 (-19.67*)	-2293.4 (-19.67*)	-2293.4 (-19.67*)
D ₂	179.725 (4.61*)	182.066 (4.76*)	188.805 (4.97*)
D ₃	71.362 (1.92***)	76.418 (2.05**)	71.435 (1.92***)
D ₄	24.149 (1.07)	24.416 (1.09)	24.272 (1.08)
D ₅	-22.492 (-1.00)	-23.364 (-1.04)	-22.428 (-1.00)
D ₆	28.473 (1.04)	27.463 (1.00)	27.963 (1.02)
D _{T-5}	-127.53 (-3.69*)	-128.40 (-3.71*)	-128.14 (-3.71*)
D _{T-4}	-55.940 (-1.75***)	-56.478 (-1.77***)	-56.364 (-1.77***)
D _{T-3}	-169.81 (-5.48*)	-170.38 (-5.50*)	-170.30 (-5.50*)
D _{T-2}	-172.36 (-5.08*)	-173.21 (-5.10*)	-172.95 (-5.10*)
D _{T-1}	-235.04 (-6.72*)	-236.07 (-6.75*)	-235.66 (-6.74*)
D _T	-456.90 (-13.55*)	-458.42 (-13.58*)	-457.79 (-13.56*)
Panel B: Corn			
Intercept	14.845 (17.29*)	16.087 (17.02*)	14.837 (16.06*)
GK Volatility	-0.013 (-0.08)		
Returns Volatility		-1.400 (-3.30*)	
Realized Volatility			-0.002 (-0.34)
Volume	0.018 (2.11**)	0.020 (2.29**)	0.018 (2.18**)
Depth	0.921 (195.92*)	0.920 (193.84*)	0.921 (176.19*)
D ₁	54.275 (3.66*)	53.385 (3.61*)	54.251 (3.68*)
D ₂	-17.555 (-2.31**)	-18.872 (-3.00*)	-16.681 (-2.32**)
D ₃	4.564 (0.81)	8.560 (1.50)	4.548 (0.81)
D ₄	6.490 (1.34)	7.411 (1.54)	6.458 (1.34)
D ₅	-2.022 (-0.42)	-1.578 (-0.33)	-2.045 (-0.42)
D ₆	1.772 (0.32)	2.207 (0.40)	1.754 (0.32)
D _{T-5}	4.370 (0.95)	4.388 (0.95)	4.364 (0.94)
D _{T-4}	2.588 (0.66)	2.590 (0.66)	2.587 (0.66)
D _{T-3}	-3.400 (-0.81)	-3.412 (-0.81)	-3.403 (-0.80)
D _{T-2}	3.986 (0.93)	4.161 (0.97)	3.983 (0.94)
D _{T-1}	5.685 (1.25)	5.948 (1.31)	5.680 (1.25)
D _T	3.650 (0.72)	3.881 (0.76)	3.640 (0.71)

Table 4.17 (Continued)

Panel C: Oil			
Intercept	9.374 (46.44*)	9.671 (47.67*)	9.337 (42.48*)
GK Volatility	-0.011 (-4.12*)		
Returns Volatility		-0.397 (-8.75*)	
Realized Volatility			-0.001 (-4.46*)
Volume	0.003 (20.11*)	0.003 (20.16*)	0.003 (19.33*)
Depth	0.782 (158.02*)	0.783 (158.56*)	0.783 (146.41*)
D ₁	-8.929 (-4.65*)	-8.975 (-4.67*)	-8.927 (-4.65*)
D ₂	-2.458 (-2.40**)	-2.109 (-2.04**)	-2.355 (-2.28**)
D ₃	0.032 (0.03)	0.337 (0.31)	0.049 (0.05)
D ₄	-2.412 (-2.46**)	-2.353 (-2.40**)	-2.407 (-2.46**)
D ₅	-0.709 (-0.56)	-0.702 (-0.55)	-0.699 (-0.55)
D ₆	-0.765 (-0.71)	-0.779 (-0.72)	-0.755 (-0.70)
D _{T-5}	-0.069 (-0.06)	-0.162 (-0.15)	-0.064 (-0.06)
D _{T-4}	1.683 (1.44)	1.581 (1.35)	1.690 (1.45)
D _{T-3}	0.882 (0.84)	0.823 (0.78)	0.885 (0.84)
D _{T-2}	0.723 (0.62)	0.657 (0.57)	0.731 (0.63)
D _{T-1}	-1.642 (-1.63)	-1.736 (-1.72***)	-1.635 (-1.62)
D _T	0.780 (0.82)	0.710 (0.75)	0.787 (0.83)
Panel D: Euro			
Intercept	9.017 (25.03*)	10.099 (25.84*)	8.955 (25.88*)
GK Volatility	-0.091 (-6.64*)		
Returns Volatility		-2.712 (-8.91*)	
Realized Volatility			-0.008 (-5.80*)
Volume	0.001 (5.33*)	0.002 (6.25*)	0.001 (5.29*)
Depth	0.973 (889.68*)	0.972 (874.78*)	0.974 (921.88*)
D ₁	19.394 (4.73*)	18.804 (4.59*)	19.302 (4.71*)
D ₂	34.692 (10.90*)	34.776 (10.95*)	34.802 (10.95*)
D ₃	16.120 (5.21*)	16.036 (5.18*)	16.144 (5.22*)
D ₄	11.988 (5.28*)	11.780 (5.18*)	12.022 (5.30*)
D ₅	7.824 (3.77*)	7.640 (3.67*)	7.841 (3.78*)
D ₆	10.213 (3.67*)	9.989 (3.59*)	10.249 (3.68*)
D _{T-5}	-9.404 (-5.24*)	-9.807 (-5.45*)	-9.453 (-5.27*)
D _{T-4}	-7.209 (-4.13*)	-7.613 (-4.34*)	-7.247 (-4.14*)
D _{T-3}	-9.982 (-5.61*)	-10.407 (-5.81*)	-9.912 (-5.58*)
D _{T-2}	-10.134 (-5.48*)	-10.858 (-5.85*)	-10.263 (-5.55*)
D _{T-1}	-5.602 (-2.21**)	-6.026 (-2.36**)	-5.522 (-2.18**)
D _T	-17.185 (-5.82*)	-17.895 (-6.06*)	-17.197 (-5.83*)

Table 4.17 (Continued)

Panel E: Yen			
Intercept	4.410 (16.95*)	5.060 (17.77*)	4.375 (17.71*)
GK Volatility	-0.044 (-3.06*)		
Returns Volatility		-1.587 (-6.48*)	
Realized Volatility			-0.003 (-1.87***)
Volume	-0.002 (-5.53*)	-0.002 (-4.59*)	-0.002 (-5.72*)
Depth	0.989 (1341.72*)	0.989 (1314.68*)	0.989 (1405.57*)
D ₁	53.699 (15.44*)	53.689 (15.42*)	53.701 (15.44*)
D ₂	27.932 (9.59*)	28.050 (9.63*)	27.996 (9.62*)
D ₃	20.605 (8.56*)	20.556 (8.54*)	20.633 (8.58*)
D ₄	14.918 (7.94*)	14.886 (7.93*)	14.935 (7.95*)
D ₅	9.683 (4.68*)	9.641 (4.67*)	9.702 (4.69*)
D ₆	3.163 (1.67***)	3.162 (1.67***)	3.178 (1.68***)
D _{T-5}	-8.215 (-6.25*)	-8.234 (-6.25*)	-8.208 (-6.24*)
D _{T-4}	-4.029 (-2.87*)	-4.063 (-2.88*)	-3.991 (-2.84*)
D _{T-3}	-8.555 (-6.30*)	-8.469 (-6.21*)	-8.556 (-6.30*)
D _{T-2}	-6.562 (-5.57*)	-6.553 (-5.57*)	-6.492 (-5.50*)
D _{T-1}	-8.016 (-7.10*)	-8.177 (-7.26*)	-8.015 (-7.09*)
D _T	-6.967 (-6.31*)	-7.084 (-6.44*)	-6.988 (-6.34*)
Panel F: Gold			
Intercept	14.705 (66.97*)	15.601 (66.89*)	14.645 (62.91*)
GK Volatility	-0.049 (-5.11*)		
Returns Volatility		-1.330 (-12.20*)	
Realized Volatility			-0.001 (-1.44)
Volume	0.004 (15.59*)	0.004 (16.87*)	0.004 (13.93*)
Depth	0.777 (237.50*)	0.773 (234.56*)	0.778 (229.88*)
D ₁	-12.314 (-5.91*)	-12.661 (-6.09*)	-12.316 (-5.91*)
D ₂	-3.690 (-2.25**)	-3.023 (-1.82***)	-3.777 (-2.30**)
D ₃	-5.569 (-4.39*)	-5.164 (-4.05*)	-5.593 (-4.40*)
D ₄	-5.395 (-3.99*)	-5.453 (-4.04*)	-5.402 (-4.00*)
D ₅	-3.881 (-3.84*)	-3.861 (-3.82*)	-3.887 (-3.84*)
D ₆	-4.460 (-3.74*)	-4.475 (-3.76*)	-4.461 (-3.74*)
D _{T-5}	-2.869 (-2.61*)	-3.143 (-2.86*)	-2.887 (-2.63*)
D _{T-4}	-0.725 (-0.55)	-0.961 (-0.73)	-0.727 (-0.55)
D _{T-3}	-4.966 (-3.60*)	-5.132 (-3.72*)	-4.983 (-3.60*)
D _{T-2}	-1.695 (-1.33)	-1.889 (-1.48)	-1.717 (-1.34)
D _{T-1}	-1.276 (-1.04)	-1.471 (-1.20)	-1.278 (-1.04)
D _T	-3.084 (-2.42**)	-3.395 (-2.67*)	-3.098 (-2.43**)

Table 4.18 Depth Frequency, Transitory Volatility, and Controls Five-Minute Night

This table presents the coefficient estimates for the following model:

$$\text{Depth Frequency}_t = \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \beta_2 \text{Frequency}_t + \beta_3 \text{Depth}_{t-1} + \sum_{i=1}^6 \phi_i D_i + \sum_{i=T-5}^T \phi_i D_i + \varepsilon_t$$

Depth frequency is calculated as the sum of the number of orders available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Frequency is computed as the quantity of trades in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-note			
Intercept	56.121 (43.29*)	55.757 (42.86*)	55.324 (33.95*)
GK Volatility	-22.771 (-4.04*)		
Returns Volatility		-2.867 (-2.64*)	
Realized Volatility			-0.376 (-2.04**)
Frequency	0.244 (21.71*)	0.230 (20.24*)	0.228 (17.16*)
Depth	0.034 (88.62*)	0.034 (87.74*)	0.034 (68.73*)
D ₁	-132.20 (-29.72*)	-131.73 (-29.80*)	-131.77 (-29.64*)
D ₂	-22.439 (-7.53*)	-29.232 (-11.68*)	-26.694 (-9.64*)
D ₃	-30.220 (-9.70*)	-29.757 (-9.77*)	-30.224 (-9.75*)
D ₄	-31.669 (-10.20*)	-31.945 (-10.08*)	-31.940 (-9.94*)
D ₅	-31.856 (-10.02*)	-32.196 (-9.84*)	-32.080 (-9.71*)
D ₆	-30.049 (-9.02*)	-29.774 (-8.90*)	-29.758 (-8.78*)
D _{T-5}	-42.810 (-10.73*)	-42.474 (-10.65*)	-42.546 (-10.66*)
D _{T-4}	-42.526 (-10.79*)	-42.443 (-10.73*)	-42.535 (-10.75*)
D _{T-3}	-41.733 (-11.90*)	-41.567 (-11.82*)	-41.658 (-11.76*)
D _{T-2}	-41.232 (-11.38*)	-40.985 (-11.29*)	-41.060 (-11.23*)
D _{T-1}	-45.639 (-12.71*)	-45.314 (-12.62*)	-45.367 (-12.55*)
D _T	-63.580 (-19.38*)	-62.981 (-19.18*)	-63.037 (-19.04*)
Panel B: Corn			
Intercept	16.611 (18.17*)	17.493 (18.54*)	16.537 (13.73*)
GK Volatility	-0.125 (-4.51*)		
Returns Volatility		-1.111 (-11.09*)	
Realized Volatility			0.000 (0.32)
Frequency	-0.021 (-5.56*)	-0.019 (-5.16*)	-0.024 (-5.89*)
Depth	0.099 (18.44*)	0.098 (18.30*)	0.099 (13.96*)
D ₁	13.205 (6.14*)	12.850 (6.03*)	13.883 (6.29*)
D ₂	4.745 (3.59*)	1.233 (1.08)	2.072 (1.56)
D ₃	4.542 (3.82*)	7.237 (5.78*)	4.151 (3.44*)
D ₄	3.891 (3.48*)	4.316 (3.83*)	3.639 (3.16*)
D ₅	2.211 (2.00**)	2.337 (2.12**)	2.047 (1.78***)
D ₆	2.277 (2.15**)	2.452 (2.30**)	2.158 (1.96**)
D _{T-5}	-3.063 (-3.53*)	-3.099 (-3.57*)	-3.116 (-3.53*)
D _{T-4}	-3.292 (-3.54*)	-3.302 (-3.57*)	-3.297 (-3.52*)
D _{T-3}	-3.238 (-3.32*)	-3.283 (-3.37*)	-3.270 (-3.34*)
D _{T-2}	-3.308 (-3.53*)	-3.201 (-3.41*)	-3.331 (-3.54*)
D _{T-1}	-2.551 (-2.49**)	-2.387 (-2.33**)	-2.583 (-2.50**)
D _T	-3.086 (-3.14*)	-2.994 (-3.05*)	-3.137 (-3.17*)

Table 4.18 (Continued)

Panel C: Oil			
Intercept	11.956 (69.67*)	11.817 (69.66*)	11.957 (58.03*)
GK Volatility	0.001 (0.62)		
Returns Volatility		0.171 (6.30*)	
Realized Volatility			0.000 (1.32)
Frequency	0.006 (19.23*)	0.006 (18.70*)	0.006 (18.16*)
Depth	0.204 (44.86*)	0.203 (45.06*)	0.204 (37.60*)
D ₁	-8.369 (-23.93*)	-8.352 (-24.00*)	-8.369 (-23.76*)
D ₂	-6.269 (-20.39*)	-6.454 (-20.55*)	-6.311 (-20.22*)
D ₃	-5.846 (-24.45*)	-5.987 (-23.66*)	-5.853 (-24.11*)
D ₄	-6.224 (-22.32*)	-6.252 (-22.52*)	-6.224 (-22.11*)
D ₅	-5.947 (-19.68*)	-5.951 (-19.71*)	-5.948 (-19.53*)
D ₆	-5.901 (-20.96*)	-5.896 (-20.93*)	-5.902 (-20.77*)
D _{T-5}	-3.972 (-10.65*)	-3.933 (-10.57*)	-3.971 (-10.56*)
D _{T-4}	-3.975 (-12.22*)	-3.931 (-12.12*)	-3.975 (-12.09*)
D _{T-3}	-4.626 (-13.79*)	-4.602 (-13.78*)	-4.625 (-13.65*)
D _{T-2}	-5.154 (-17.29*)	-5.127 (-17.24*)	-5.154 (-17.07*)
D _{T-1}	-5.816 (-17.41*)	-5.779 (-17.38*)	-5.817 (-17.24*)
D _T	-6.294 (-21.40*)	-6.264 (-21.40*)	-6.293 (-21.16*)
Panel D: Euro			
Intercept	12.414 (18.51*)	13.825 (20.74*)	12.404 (15.41*)
GK Volatility	-0.064 (-3.94*)		
Returns Volatility		-3.467 (-9.78*)	
Realized Volatility			-0.007 (-5.14*)
Frequency	0.044 (26.84*)	0.045 (26.89*)	0.044 (25.08*)
Depth	0.198 (111.03*)	0.197 (109.91*)	0.198 (86.81*)
D ₁	-8.465 (-8.91*)	-9.006 (-9.57*)	-8.483 (-8.61*)
D ₂	-6.606 (-7.05*)	-6.505 (-6.88*)	-6.526 (-6.69*)
D ₃	-11.166 (-11.13*)	-11.279 (-11.29*)	-11.161 (-10.81*)
D ₄	-14.320 (-14.56*)	-14.609 (-14.88*)	-14.310 (-14.16*)
D ₅	-15.785 (-16.67*)	-16.026 (-17.05*)	-15.781 (-16.23*)
D ₆	-16.043 (-16.94*)	-16.362 (-17.33*)	-16.032 (-16.47*)
D _{T-5}	-11.107 (-14.33*)	-11.446 (-14.78*)	-11.102 (-13.66*)
D _{T-4}	-10.271 (-12.49*)	-10.654 (-12.80*)	-10.275 (-11.93*)
D _{T-3}	-9.744 (-12.48*)	-10.198 (-12.79*)	-9.664 (-11.68*)
D _{T-2}	-9.336 (-12.00*)	-10.021 (-13.17*)	-9.381 (-11.48*)
D _{T-1}	-8.850 (-11.06*)	-9.306 (-11.70*)	-8.763 (-10.32*)
D _T	-13.556 (-18.30*)	-14.345 (-19.84*)	-13.541 (-17.24*)

Table 4.18 (Continued)

Panel E: Yen			
Intercept	19.138 (39.57*)	20.579 (41.46*)	19.056 (32.33*)
GK Volatility	-0.106 (-9.13*)		
Returns Volatility		-3.806 (-12.86*)	
Realized Volatility			-0.006 (-5.52*)
Frequency	0.064 (39.81*)	0.066 (40.48*)	0.064 (35.11*)
Depth	0.158 (131.64*)	0.157 (130.92*)	0.158 (101.59*)
D ₁	-17.120 (-31.12*)	-17.015 (-28.40*)	-17.139 (-28.20*)
D ₂	-20.055 (-31.82*)	-19.681 (-31.55*)	-19.926 (-29.65*)
D ₃	-20.891 (-28.18*)	-20.935 (-28.47*)	-20.831 (-26.89*)
D ₄	-22.179 (-28.63*)	-22.194 (-28.71*)	-22.144 (-27.50*)
D ₅	-23.254 (-28.13*)	-23.302 (-28.31*)	-23.209 (-27.25*)
D ₆	-24.311 (-30.30*)	-24.270 (-30.31*)	-24.275 (-29.31*)
D _{T-5}	-18.580 (-34.89*)	-18.533 (-32.38*)	-18.574 (-31.56*)
D _{T-4}	-17.942 (-33.04*)	-17.929 (-30.04*)	-17.887 (-29.51*)
D _{T-3}	-18.499 (-34.40*)	-18.193 (-29.51*)	-18.520 (-31.09*)
D _{T-2}	-17.753 (-35.11*)	-17.631 (-31.04*)	-17.622 (-30.51*)
D _{T-1}	-17.765 (-36.80*)	-18.051 (-35.95*)	-17.782 (-32.30*)
D _T	-18.561 (-39.31*)	-18.748 (-37.34*)	-18.633 (-34.67*)
Panel F: Gold			
Intercept	14.585 (122.57*)	14.815 (122.52*)	14.540 (104.45*)
GK Volatility	-0.051 (-9.80*)		
Returns Volatility		-0.432 (-11.33*)	
Realized Volatility			-0.002 (-6.65*)
Frequency	0.005 (14.02*)	0.005 (13.86*)	0.005 (11.11*)
Depth	0.161 (91.92*)	0.160 (90.70*)	0.162 (78.27*)
D ₁	-9.937 (-25.97*)	-10.053 (-26.27*)	-9.927 (-25.75*)
D ₂	-7.974 (-29.75*)	-7.829 (-28.52*)	-8.032 (-29.39*)
D ₃	-7.606 (-23.63*)	-7.489 (-23.11*)	-7.624 (-23.45*)
D ₄	-7.399 (-29.15*)	-7.417 (-29.33*)	-7.406 (-28.74*)
D ₅	-7.014 (-25.54*)	-7.006 (-25.51*)	-7.021 (-25.14*)
D ₆	-7.023 (-26.03*)	-7.022 (-25.94*)	-7.024 (-25.56*)
D _{T-5}	-5.237 (-18.68*)	-5.338 (-19.18*)	-5.243 (-18.55*)
D _{T-4}	-5.409 (-20.68*)	-5.484 (-21.10*)	-5.404 (-20.38*)
D _{T-3}	-6.169 (-20.55*)	-6.235 (-20.78*)	-6.173 (-20.36*)
D _{T-2}	-7.003 (-25.65*)	-7.083 (-26.05*)	-7.012 (-25.33*)
D _{T-1}	-7.427 (-24.57*)	-7.484 (-24.78*)	-7.429 (-24.30*)
D _T	-8.012 (-27.00*)	-8.123 (-27.55*)	-8.012 (-26.70*)

Table 4.19 Depth Quantity, Transitory Volatility, and Controls Fifteen-Minute Night

This table presents the coefficient estimates for the following model:

$$Depth\ Quantity_t = \alpha_0 + \beta_1 Volatility_{t-1} + \beta_2 Volume_t + \beta_3 Depth_{t-1} + \sum_{i=1}^2 \phi_i D_i + \sum_{i=T-1}^T \phi_i D_i + \varepsilon_t$$

Depth quantity is calculated as the sum of the depth available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Volume is computed as the sum of trade volume in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-note			
Intercept	194.694 (16.43*)	211.171 (18.88*)	189.206 (18.03*)
GK Volatility	-28.199 (-1.24)		
Returns Volatility		-81.317 (-6.11*)	
Realized Volatility			-2.757 (-2.67*)
Volume	0.021 (6.48*)	0.024 (7.41*)	0.020 (6.87*)
Depth	0.947 (241.02*)	0.946 (252.26*)	0.948 (257.27*)
D ₁	-2441.1 (-20.53*)	-2437.8 (-20.43*)	-2442.1 (-20.50*)
D ₂	203.094 (5.00*)	178.697 (4.19*)	213.034 (5.18*)
D _{T-1}	-323.68 (-6.88*)	-328.09 (-6.98*)	-325.56 (-6.91*)
D _T	-638.02 (-13.52*)	-639.51 (-13.50*)	-638.69 (-13.46*)
Panel B: Corn			
Intercept	22.566 (12.29*)	23.568 (12.06*)	22.383 (10.60*)
GK Volatility	-0.066 (-0.82)		
Returns Volatility		-0.848 (-1.80***)	
Realized Volatility			0.003 (0.56)
Volume	0.022 (3.47*)	0.023 (3.52*)	0.021 (3.41*)
Depth	0.870 (83.62*)	0.870 (83.33*)	0.870 (71.81*)
D ₁	34.018 (2.44**)	33.399 (2.38**)	34.959 (2.51**)
D ₂	0.296 (0.04)	-3.216 (-0.48)	-4.081 (-0.56)
D _{T-1}	5.170 (1.14)	5.135 (1.13)	5.141 (1.13)
D _T	9.484 (1.97**)	9.511 (1.97**)	9.544 (1.98**)
Panel C: Oil			
Intercept	11.093 (33.88*)	11.385 (35.46*)	11.008 (32.88*)
GK Volatility	-0.008 (-2.62*)		
Returns Volatility		-0.301 (-8.18*)	
Realized Volatility			-0.001 (-2.87*)
Volume	0.001 (19.90*)	0.001 (20.47*)	0.001 (19.89*)
Depth	0.736 (92.36*)	0.739 (92.96*)	0.737 (90.84*)
D ₁	-7.838 (-6.52*)	-7.972 (-6.61*)	-7.831 (-6.49*)
D ₂	-1.131 (-1.05)	-0.954 (-0.88)	-1.005 (-0.93)
D _{T-1}	0.044 (0.04)	-0.125 (-0.12)	0.049 (0.05)
D _T	-0.888 (-0.75)	-1.058 (-0.90)	-0.881 (-0.75)

Table 4.19 (Continued)

Panel D: Euro			
Intercept	13.034 (16.26*)	17.614 (19.09*)	12.530 (16.78*)
GK Volatility	-0.221 (-7.25*)		
Returns Volatility		-6.888 (-12.58*)	
Realized Volatility			-0.013 (-6.87*)
Volume	0.002 (10.55*)	0.003 (11.92*)	0.002 (10.25*)
Depth	0.952 (348.25*)	0.947 (338.23*)	0.953 (368.66*)
D ₁	42.510 (9.79*)	40.153 (9.22*)	42.087 (9.73*)
D ₂	46.107 (12.14*)	45.691 (12.01*)	46.354 (12.29*)
D _{T-1}	-20.171 (-9.00*)	-22.520 (-10.14*)	-20.355 (-9.18*)
D _T	-18.714 (-8.48*)	-21.808 (-9.87*)	-19.149 (-8.64*)
Panel E: Yen			
Intercept	5.118 (8.52*)	8.654 (12.18*)	4.847 (9.16*)
GK Volatility	-0.123 (-3.87*)		
Returns Volatility		-5.284 (-11.43*)	
Realized Volatility			-0.005 (-1.95***)
Volume	0.001 (2.44**)	0.002 (4.62*)	0.001 (2.13**)
Depth	0.979 (500.12*)	0.976 (481.74*)	0.980 (544.00*)
D ₁	77.552 (17.75*)	76.438 (17.50*)	77.374 (17.80*)
D ₂	52.788 (16.10*)	53.282 (16.33*)	52.947 (16.17*)
D _{T-1}	-14.293 (-9.06*)	-14.999 (-9.41*)	-14.463 (-9.13*)
D _T	-13.281 (-8.68*)	-14.096 (-9.04*)	-13.275 (-8.63*)
Panel F: Gold			
Intercept	16.665 (42.20*)	17.437 (43.50*)	16.362 (39.18*)
GK Volatility	-0.083 (-5.65*)		
Returns Volatility		-0.940 (-9.78*)	
Realized Volatility			-0.003 (-2.73*)
Volume	0.002 (10.29*)	0.002 (10.23*)	0.002 (8.79*)
Depth	0.745 (130.89*)	0.743 (130.13*)	0.748 (129.38*)
D ₁	-11.722 (-7.24*)	-12.052 (-7.43*)	-11.674 (-7.17*)
D ₂	-5.307 (-4.13*)	-5.060 (-3.92*)	-5.394 (-4.19*)
D _{T-1}	-2.306 (-1.99**)	-2.557 (-2.22**)	-2.269 (-1.96**)
D _T	-2.328 (-1.63)	-2.542 (-1.77***)	-2.316 (-1.62)

Table 4.20 Depth Frequency, Transitory Volatility, and Controls Fifteen-Minute Night

This table presents the coefficient estimates for the following model:

$$\text{Depth Frequency}_t = \alpha_0 + \beta_1 \text{Volatility}_{t-1} + \beta_2 \text{Frequency}_t + \beta_3 \text{Depth}_{t-1} + \sum_{i=1}^2 \phi_i D_i + \sum_{i=T-1}^T \phi_i D_i + \varepsilon_t$$

Depth frequency is calculated as the sum of the number of orders available across all five levels. GK volatility is the Garman and Klass volatility (1980) measure composed of the high, low, open, and close values in an interval. Returns volatility is calculated as the absolute value of returns across intervals. Realized volatility is the sum of squared returns in each interval. Frequency is computed as the quantity of trades in each time interval. D is a dummy variable for the time interval that takes a value of one or zero. Each regression is estimated using Hansen's (1982) generalized method of moments (GMM) procedure along with the Newey and West (1987) correction. The T subscript represents the last time interval of a trading day. *, **, and *** denote significance at the one percent level, five percent level, and ten percent level, respectively.

Panel A: T-note			
Intercept	57.712 (29.65*)	56.344 (28.83*)	55.794 (24.32*)
GK Volatility	-14.341 (-5.37*)		
Returns Volatility		-2.627 (-2.24**)	
Realized Volatility			-0.164 (-1.25)
Frequency	0.107 (15.41*)	0.097 (13.99*)	0.095 (13.12*)
Depth	0.033 (54.92*)	0.033 (54.83*)	0.033 (45.00*)
D ₁	-123.75 (-28.08*)	-124.03 (-28.20*)	-124.15 (-27.98*)
D ₂	-17.256 (-5.79*)	-22.538 (-8.14*)	-21.005 (-7.02*)
D _{T-1}	-48.360 (-12.57*)	-48.940 (-12.66*)	-48.933 (-12.43*)
D _T	-61.136 (-17.36*)	-60.967 (-17.20*)	-61.029 (-17.09*)
Panel B: Corn			
Intercept	16.228 (10.67*)	16.843 (10.93*)	16.105 (8.20*)
GK Volatility	-0.059 (-3.61*)		
Returns Volatility		-0.565 (-6.29*)	
Realized Volatility			0.001 (1.41)
Frequency	-0.010 (-4.11*)	-0.009 (-3.86*)	-0.012 (-4.71*)
Depth	0.101 (11.35*)	0.100 (11.34*)	0.101 (8.75*)
D ₁	12.846 (6.40*)	12.510 (6.19*)	13.722 (6.72*)
D ₂	4.949 (3.43*)	2.050 (1.69***)	2.102 (1.63)
D _{T-1}	-2.333 (-2.68*)	-2.368 (-2.71*)	-2.357 (-2.71*)
D _T	-1.840 (-1.97**)	-1.824 (-1.95***)	-1.768 (-1.92***)
Panel C: Oil			
Intercept	11.267 (44.99*)	11.112 (45.23*)	11.299 (42.43*)
GK Volatility	0.004 (2.23**)		
Returns Volatility		0.160 (6.93*)	
Realized Volatility			0.001 (3.19*)
Frequency	0.002 (18.68*)	0.002 (18.64*)	0.002 (18.36*)
Depth	0.209 (32.24*)	0.208 (32.29*)	0.208 (29.98*)
D ₁	-7.626 (-25.37*)	-7.558 (-25.39*)	-7.627 (-25.15*)
D ₂	-5.626 (-21.40*)	-5.729 (-21.42*)	-5.818 (-20.59*)
D _{T-1}	-4.345 (-13.10*)	-4.258 (-12.99*)	-4.340 (-13.00*)
D _T	-5.959 (-20.24*)	-5.873 (-20.21*)	-5.955 (-20.09*)

Table 4.20 (Continued)

Panel D: Euro			
Intercept	9.382 (9.41*)	11.851 (12.09*)	9.194 (7.92*)
GK Volatility	-0.085 (-5.31*)		
Returns Volatility		-3.734 (-12.17*)	
Realized Volatility			-0.004 (-4.32*)
Frequency	0.019 (24.39*)	0.019 (24.62*)	0.019 (22.78*)
Depth	0.192 (70.06*)	0.189 (69.68*)	0.192 (56.84*)
D ₁	-1.578 (-1.70***)	-2.623 (-2.87*)	-1.780 (-1.81***)
D ₂	-4.844 (-4.67*)	-5.067 (-4.84*)	-4.758 (-4.42*)
D _{T-1}	-9.054 (-9.62*)	-10.067 (-10.86*)	-9.183 (-9.24*)
D _T	-8.821 (-9.93*)	-10.245 (-11.88*)	-9.031 (-9.55*)
Panel E: Yen			
Intercept	14.691 (19.33*)	16.954 (21.49*)	14.445 (16.23*)
GK Volatility	-0.117 (-7.40*)		
Returns Volatility		-3.886 (-12.49*)	
Realized Volatility			-0.003 (-3.45*)
Frequency	0.028 (30.57*)	0.029 (32.34*)	0.028 (26.84*)
Depth	0.157 (84.57*)	0.155 (84.25*)	0.157 (68.09*)
D ₁	-8.274 (-11.45*)	-8.921 (-12.17*)	-8.517 (-10.66*)
D ₂	-12.688 (-16.57*)	-12.156 (-16.23*)	-12.568 (-15.39*)
D _{T-1}	-15.108 (-21.76*)	-15.473 (-21.37*)	-15.312 (-19.85*)
D _T	-14.750 (-21.58*)	-15.191 (-21.37*)	-14.834 (-19.28*)
Panel F: Gold			
Intercept	13.606 (71.69*)	13.700 (72.36*)	13.451 (62.58*)
GK Volatility	-0.054 (-8.24*)		
Returns Volatility		-0.251 (-7.73*)	
Realized Volatility			-0.003 (-5.86*)
Frequency	0.002 (7.97*)	0.002 (7.21*)	0.002 (6.24*)
Depth	0.173 (62.28*)	0.174 (61.91*)	0.175 (55.65*)
D ₁	-8.991 (-26.41*)	-9.081 (-26.54*)	-8.967 (-25.79*)
D ₂	-6.764 (-24.20*)	-6.761 (-23.96*)	-6.824 (-23.57*)
D _{T-1}	-5.156 (-19.61*)	-5.229 (-19.97*)	-5.144 (-19.07*)
D _T	-7.196 (-23.40*)	-7.270 (-23.37*)	-7.201 (-22.67*)

CHAPTER 5: CONCLUSION

Past research shows that depth beyond the best level is important in samples of equity and international futures markets. Yet, little research has focused on depth beyond the first level in the U.S. futures markets. Until recently, U.S. futures markets were limited to floor trading where depth was either not recorded or not made available. This dissertation employs the Chicago Mercantile Exchange (CME) Group proprietary database on five-deep depth to analyze the characteristics of depth in U.S. electronic futures markets in relation to distribution, spread, and volatility.

Chapter 2 examines the characteristics of depth for six futures contracts within the context of a five-deep limit order book. Results show that a large amount of depth is present in the book beyond the best level. The amount of depth across the five levels is found to be unequal for all contracts. In addition, the amount of depth excluding the best level is found to be uneven for all but the T-note futures contract. Chapter 3 examines the relation between bid-ask spread and five-deep market depth. Evidence is found to support an inverse relation between the spread and depth after controlling for known control factors. Chapter 4 explores volatility in relation to depth in the limit order book. Overall, an inverse relation is found between volatility and depth. In conclusion these results contribute to the understating of the dynamics of depth in U.S. futures markets.

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