Depth Characteristics for the Electronic Futures Limit Order Book

Alexandre Aidov Assistant Professor of Finance School of Business Administration Brazos Hall – Room 316 14000 University Boulevard Sugar Land, TX 77479 University of Houston-Victoria 281-275-8882 aidova@uhv.edu

Robert T. Daigler* Knight Ridder Research Professor of Finance Department of Finance and Real Estate RB208B Chapman Graduate School of Business Florida International University Miami, FL 33199 daiglerr@fiu.edu 954-434-2412

• Corresponding Author:

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We are indebted to Mark Holder and the CME Group for providing us with the futures market depth data.

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Abstract

Prior literature lacks a comprehensive characterization of depth in U.S. futures markets due to past limitations on the availability of depth data from floor trading records. Electronic markets remedy the lack of depth data, providing information on depth from the limit order book. This study employs the Chicago Mercantile Exchange's (CME) proprietary depth database, which provides the five-deep depth limit order book. We examine the duration, symmetry, and equality of depth for both the day and night trading sessions. The results show that a large amount of depth is present in the book beyond the best bid-ask level. Furthermore, we show that depth is updated faster during the day than the night session. We document symmetry between the bid and ask sides of the limit order book for each of the separate five depth levels. However, the total amount of bid plus ask depth differs from one level to another. Overall, our characterization of depth helps explain the behavior of market participants in their order submission strategies.

1. Introduction

Liquidity is an important characteristic for efficient financial markets. 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. Therefore, a deep market is one where large orders do not shift prices significantly.

The modern definition of depth is the ability to buy or sell a certain amount of an asset without substantially affecting the quoted price. This ability is often quantified as the depth available to trade at the bid and ask prices. However, due to data constraints and availability, prior literature interprets and quantifies depth in different ways. When the quantity of depth is not available, researchers have proposed proxies for depth, such as open interest.¹ When depth data is available, it is often restricted to the first bid-ask level.² Improvements in data collection and increases in market transparency led to the dissemination of limit order book data, with depth quantified as the entire limit order book rather than simply at the best bid-ask level. However, the literature employing limit order book data has been limited to equities and international futures markets. Moreover, the analysis of depth in the limit order book for U.S. futures markets is absent from prior research due to lack of availability. In particular, depth data for floor-traded U.S. futures markets are unavailable for study because such data is not collected from individual floor trader's books. Alternatively, with the advent of electronic trading, depth data in the limit order for electronic U.S. futures markets is now available. In this research, we employ a proprietary dataset for U.S. futures contracts containing a limit order book with five levels of depth.

The use of multi-level limit order book depth (as opposed to the best bid-ask depth) is important for several reasons. The multi-level limit order book describes how much depth is allocated at *each* price level, with prior studies confirming that depth using the entire limit order book is informative (see Cao, Hansch, and Wang (2009)). In particular, limit order book depth illustrates how much trading interest exists, as well as the degree of order flow at each particular price level. Therefore, an understanding of the depth characteristics in the limit order book is essential for market participants to trade effectively. 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

¹ For example, Ragunathan and Peker (1997) examine currency and interest rate futures and Fung and Patterson (2001) examine interest rate and index futures. Both studies employ open interest as a proxy for depth.

² For example, see Vo (2007), Frino, Lepone, and Wearin (2008), and Chordia, Roll, and Subrahmanyam (2011).

specific transaction size can be calculated resulting in a measure of the price elasticities of supply and demand.

Prior theoretical literature hypothesizes that the size of depth in the limit order book affects the trading behavior and order submissions tactics of market participants. For example, Parlour (1998) develops a model where the state of the limit order book affects the decision to submit a market or limit order; empirical research corroborates this theory. Cao, Hansch, and Wang (2008) conclude that market participants use depth information to choose their order placement tactics. Chiu, Chung, and Wang (2014) provide additional evidence that the state of the limit order book affects the order submission strategies of market participants. In addition, Aitken et al. (2007) show that the depth in the entire limit order book, as opposed to depth at the best level, is needed to comprehend the trading strategies of market participants.

Research has examined the characteristics of limit order book depth for several equity markets around the world.³ However, the characteristics of market depth for U.S. futures markets are unexplored. The goal of this research is to examine the characteristics of the limit order book depth in the electronic U.S. futures markets by using a proprietary database from the CME Group that includes five levels of depth. The depth characteristics of interest include duration, symmetry, and equality. Duration is the time between successive depth updates, symmetry is the balance between the bid and the ask sides of the book, and equality is the comparison of depth across the book levels. In addition, we explore the probability distributions for all five depth levels and the shape of the limit order book across six futures contracts.⁴ Unique aspects of this study are the use of electronic high-frequency data, an examination of the individual depth

³ Biais, Hillion, and Spatt (1995) analyze depth from the Paris Bourse, Niemeyer and Sandas (1995) employ the Stockholm Stock Exchange, Visaltanachoti, Charoenwong, and Ding (2008) use the Stock Exchange of Thailand, and Al-Suhaibani and Kryzanowski (2000) study the Saudi Stock Market.

⁴ The "shape" of the limit order book refers to the depth available at each price step and the difference between successive steps.

messages, and the comparison of characteristics between the day and night trading sessions. Furthermore, we document how much depth actually exists in the U.S. futures markets.

2. Literature Review

2.1. Limit Order Book

The distribution and allocation of market depth beyond the first level is a key piece of information that affects order submission strategies. In fact, the state of the limit order book is theoretically linked to the trading decisions made by market participants.⁵ Furthermore, prior literature empirically examines the relation between trader order choice and the depth allocated in the limit order book. Pascual and Veredas (2009) show that market participants rely on the state of the limit order book when trading. In order to comprehend the trading behavior of market participants, the entire limit order book is required. Aitken et al. (2007) show that many institutional investors provide depth at multiple levels simultaneously. The general conclusion of this literature is that the limit order book depth holds key information in understanding how a market participant trades. Provided that the depth in the limit order book holds pertinent information, it is vital to understand its characteristics.

2.2. Depth Characteristics

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.⁶ The distribution of depth in the limit order book was examined for stocks for exchanges in Paris, Thailand, Stockholm, and Saudi Arabia.

One of the first articles to examine the characteristics of depth in the limit order book is

⁵ See Foucault, Kadan, and Kandel (2005), Goettler, Parlour, and Rajan (2005), and Rosu (2009)

⁶ For example, stock exchanges in Tokyo, London, Frankfurt, Australia, Hong Kong, Stockholm, Toronto, plus Euronext, the London International Financial Futures Exchange, and the Sydney Futures Exchange contain electronic limit order books.

Biais, Hillion, and Spatt (1995). Using five depth levels for stocks on 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 test for the equality of depth across all five levels and for the equality of depth across the four levels excluding the best. Their evidence shows that the depth is larger at the first level relative to each of the other four levels, although the depth away from the best level does not vary significantly across each level.

Visaltanachoti, Chaoenwong, and Ding (2008) study the depth distribution for equities on the Stock Exchange of Thailand (SET). The SET displays three levels of depth to public investors and an additional three levels to exchange officials. Results show that the first three levels of publicly displayed depth on both sides of the limit order book are not significantly different from one another.

Similarly, Niemeyer and Sandas (1995) examine depth on the Stockholm Stock Exchange using data which contains five levels of depth on the bid and ask sides of the book. Their results show that depth down the limit order book levels is unequal and depth between the bid and ask sides of the book is also not equal. In terms of shape, they find that depth is concentrated at the first level and decreases further out along the 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. On average, they also show that depths are larger on the bid side of the book. In sum, previous research explores the characteristics of depth for international equity markets. However, the U.S. futures markets is an unexplored area of research in terms of depth.

2.3. Around the Clock Trading

In stark contrast to previous literature that examines equity depth characteristics, the data we employ in this research trades essentially around the clock. Studies examining "continuous" trading for futures markets focus on volatility. In particular, Martinez and Tse (2008) explore volatility for the Eurodollar, the Euro/dollar foreign exchange rate, and the E-mini S&P 500 futures contracts traded around the clock. They document that volatility is larger during the traditional U.S. trading hours relative to the rest of the hours in the trading day. Kao and Fung (2012) examine volume and volatility for Japanese Yen, euro FX, and S&P 500 futures. They show that both volatility and volume is largest during the period between 8:00 a.m. and 4:00 p.m. ET compared to the rest of the day. In effect, research shows that volatility and volume exemplify different patterns for traditional trading hours versus nontraditional hours. In addition, Fong and Liu (2010) find that limit order book revision and cancellation activities are low during periods like lunchtime, when the opportunity cost to closely follow the limit order book is high. The amount of depth in the limit order book during day (traditional) and night (nontraditional) trading hours is not examined in prior research.

2.4. Database

The Globex database and specifically the limit order book depth data that we employ is used sparingly in prior research. Deuskar and Johmson (2011) decompose aggregate risk into a component driven by orders and a component unrelated to orders. They show that the component driven by orders contributes heavily to market variance. They use book depth for the S&P 500 Emini futures contract to construct a measure of illiquidity. Christensen and Woodmansey (2013) create an algorithm to predict the hidden quantity resulting from iceberg orders and apply it to the S&P 500 E-mini futures contract.⁷ They estimate that 9% of the S&P 500 depth in the limit order book is composed of iceberg orders.

Our research is most closely related to Furfine (2012). He employs the limit order book to examine how the recent financial crisis impacted the liquidity of the Eurodollar and S&P 500 futures markets. His results show that the Eurodollar futures market suffered a greater liquidity withdrawal than the S&P 500 market. Furfine examines both the book depth and the messages associated with the depth updates. However, his entire analysis is limited to the daily 9:00 a.m. to 9:30 a.m. CT time window over his sample period. Our analysis of depth in the book features the entire around the clock trading period.

3. Data

3.1. CME Group Database

A key feature of our research is the use of the CME Group Globex database on five-deep depth data for futures markets. The data for this research is generously provided by the CME Group and results from the trading activity on the CME Globex electronic trading platform.⁸ Futures contracts trade on the CME Globex in three different modes.⁹ The futures contracts we examine trade using 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 our data comes from electronic trading since depth data

⁷ An iceberg order displays only a portion of the entire order. When the portion displayed is filled, another portion is displayed.

⁸ 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 through ClearPort. The third platform is electronic trading through the Globex trading platform.

⁹ The first mode is labeled side-by-side trading and occurs when contracts are electronically executed on the CME Globex system for the non-open outcry portion of the day, as well as simultaneously trade electronically on Globex with trading on the floor during the open outcry portion of the day. The second mode is electronic only trading, which occurs when contracts trade solely electronically on the CME Globex. The third mode is termed after-hours electronic trading, where contracts execute electronically on the CME Globex during the non-open outcry period and are solely floor traded during the open outcry period.

for floor trading is not available. We label the electronic trading during the open outcry period as "day" trading and the trading during the hours outside of the open outcry period as "night" trading.

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.¹⁰ The depth messages consists of five positions that represent each of the five depth levels and takes a value of one if a depth level is updated and zero otherwise.¹¹ In order to address potential complications due to a lack of data, a calendar date is deleted if it lands on a holiday or contains extended trading breaks either preceding or following a holiday.¹² Additionally, days with irregular depth reporting are excluded from the sample.¹³

3.2. Futures Contracts

The market depth database we create 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), the euro/U.S. dollar, yen/U.S. dollar, and gold futures. Table 1 lists the futures contracts and dates included in the database.¹⁴ The data for each futures contract begins in January 2008 and runs to March, April, or October 2009, depending on the contract.¹⁵ The ticker

 $^{^{10}}$ The granularity of the time stamp is to the nearest centisecond (1/100 of a second).

¹¹ For example, if the indictor is "10001" then the depth (quantity and/or price) changes only for the first and fifth depth levels. Alternatively, if "00100" is the change of depth indicator, then depth only changes for the third level.

¹² 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.

¹³ Irregular depth reporting is defined in two ways. First, if the first depth update occurs more than two hours after the market opens on a given calendar date, that date is deleted. Second, if the last depth update for a given calendar date occurs before the end of the open outcry portion of the day, then that calendar date is deleted from the database. ¹⁴ 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."

¹⁵ 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

symbols listed in Table 1 correspond to the contract symbol for electronic trading. The original size of the RLC encoded data sets for the futures contracts range from 58.1 gigabytes for the T-note futures to 1.09 terabytes for oil futures. The decoded depth files are substantially smaller with sizes between 6.34 GB for corn to 103 GB for the euro.¹⁶ The depth messages refer to the total number of depth message updates in our decoded database and range between 30,420,858 (corn) and 495,558,768 (euro) messages.

The futures contracts employed in this study are all heavily traded and represent the dominant contracts in their respective categories. Panel A in Table 2 describes the overall amount of trading activity in each contract.¹⁷ There is a large variation in the volume of trades per contract, ranging from a low of 22,749,569 for the yen futures to a high of 189,852,019 for the T-note futures contract. The table 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 we employ represents the vast majority of market activity in these contracts. In panel B, we separate the around the clock trading into a day trading component and a night trading period for each futures contract.

The six futures contracts also contain different types of contract characteristics; Table 3 summarizes these characteristics. The contract sizes are different for each contract, primarily since they are based on different types of underlying assets. 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,

exchange contracts. After this depth increases, the 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.

¹⁶ In comparison to the size of the encoded data, the size of the decoded data 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.

¹⁷ The trade activity represented in this table includes all expirations and trades for each futures contract for the year 2009.

or minimum price increments, also vary for each contract. We roll contracts over to the next expiration when trading volume in the first deferred contract exceeds volume in the nearby contract.

4. Methodology

We examine basic hypotheses concerning depth as a starting point in order to understand the characteristics of depth. In addition, our discussion of the results provides additional information concerning depth beyond our basic hypotheses, as well as a deeper analysis than found in prior literature. Past research shows that fundamental market variables exhibit varying magnitudes during day and night trading. Therefore, as a starting point, we compare market depth between the day and night trading sessions.

In our analysis best depth is defined as the number of contracts available to trade at the first depth level on both sides of the limit order book:

$$Best \ Depth = Depth_{Bid \ 1} + Depth_{Ask \ 1} \tag{1}$$

Total depth is found by summing all five levels of depth on both sides of the book:

$$Total \ Depth = \sum_{i=1}^{5} Depth_{Bid \ i} + \sum_{i=1}^{5} Depth_{Ask \ i}$$
(2)

We test the following two hypotheses:

Hypothesis 1: Best depth is not equal when comparing the day and night periods.

Hypothesis 2: Total depth is not equal for the day and night periods.

Before we establish the characteristics of depth in the electronic futures market, we summarize the depth available in the five-deep limit order book. We examine how much depth exists through the analysis of individual depth levels, aggregate depth levels, and other depth measures. There are two sides of the limit order book, the bid (buy) side and the ask (sell) side.

For the individual depth levels we quantify the number of contracts available for the first, second, third, fourth, and fifth level of depth, on each side of the limit order book:

Bid Depth
$$i = Depth_{Bid_i}$$
 and Ask Depth $i = Depth_{Ask_i}$, $i = 1, 2, 3, 4, 5$ (3)

We quantify aggregate depth in three ways: total depth, level depth, and bid (ask) depth. The total depth is defined in Equation 2. The level depth represents the sum of the depth on the bid and ask sides of the book separately at each of the five levels:

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

$$(4)$$

The bid (ask) depth represents the sum of the bid and ask depths separately across all five levels in the limit order book:

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

Additional depth measures we consider include the number of orders available at the first level and the number of orders contained in the entire five-deep book. We also consider the shape of the limit order book and the distribution of depth. These measures help examine how much depth exists and where depth is concentrated in the futures electronic limit order book.

We then establish the characteristics of depth of the limit order book. In particular we examine the duration, symmetry, and equality of depth. For the duration characteristic, we first examine the combinations of depth message updates and then the amount of time that elapses between 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 hypothesis is tested concerning the duration of depth:

Hypothesis 3: The duration of depth is not equal between the day and night periods.

For the symmetry characteristic, we explore the balance between the bid and ask sides of the book. If the depth at a certain level is symmetric then this implies the bid and ask depth at that level are equal. 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 following hypothesis is tested:

Hypothesis 4: No symmetry exists between the bid and ask depth at each level.

In order to examine the equality characteristics of depth in the limit order book, we compare the depth across all five levels, across the four levels excluding the first, and between level pairs. We first compare the equality of depth across the entire five-deep limit order book with the following hypothesis:

Hypothesis 5: Depth is not concurrently equal across all five depth levels.

Prior research shows that exclusion of the best level can affect the equality of the remaining four levels. Therefore, we test the following hypothesis:

Hypothesis 6: Depth is not concurrently equal across all four depth levels excluding the best level.

We also test the following hypothesis to examine the pairwise equality of any two depth levels:

Hypothesis 7: Depth is not equal across any two depth levels.

These propositions help elucidate the allocation of depth in the five-deep electronic limit order book in U.S. futures markets.

5. Results

5.1. Day and Night Depth

The intraday pattern of cumulative depth across the book is provided in Figure 1. By inspection, there is a larger amount of depth during the day trading hours (typically between 7:00 and 14:00) relative to the night hours for all futures contracts. Table 4 presents results for the comparison of depth between the day and night trading periods. We find evidence that the best depth in Panel A and total depth in Panel B reflect differences in the amount of depth present

during day and night trading periods. In light of this evidence, we consider the characteristics of depth separately for day and night trading in the ensuing analysis.

5.2. Summary Statistics

Prior to discussing the characteristics of depth, we summarize the extent to which depth is available in the five-deep limit order book. Table 5 presents the summary statistics for each depth level on each side of the book, separately for day and night periods. The amount of depth at each level beyond the first is at least double the depth at the first level for T-note, euro, and yen futures, and slightly less than half for corn, oil, and gold. For instance, the average day depth for the T-note futures at levels one through five are 404.44, 900.86, 951.35, 921.24, and 925.73, respectively. This pattern holds on both sides of the book for both the day and night trading periods. In other words, a significant amount of depth exists beyond the first depth level. Similar to Cao, Hansch, and Wang (2009), we document that at least 88% (depending on the futures contract) of total book depth is allocated at levels beyond the first level. Table 6 provides the aggregate depth summary for each level (both sides of the book), along each side of the book, and the total depth. Both the average depth measures and their standard deviations are larger during the day than at night for most contracts.¹⁸ Although not a direct comparison due to different contract specifications, the largest average total day depth is for the T-note futures at 8,143.61 and the smallest is for the oil futures at 101.83. The difference between the sum of the depth on the bid and ask sides of the book is larger during the day than at night. Table 7 presents a summary on the number of orders for the first level and for the complete book. The average total depth per total orders is larger than the average best depth per best orders for all contracts except for oil and gold futures.

¹⁸ The standard deviation for gold futures is nearly identical for the day and night periods. For oil futures, the standard deviation is smaller for the day than the night, but only for the first two depth levels.

Table 8 presents the comparison of the moments for the day and night sessions. During the day, oil futures (3.46) possess the largest and corn futures (1.52) have the smallest dispersion of the best depth levels. In addition, gold futures (2.56) have the largest and yen futures (1.63) the smallest dispersion of total depth during the day. For the night period, gold futures have the largest and corn futures have the smallest dispersion of both best and total depth. The best depth and total depth are more skewed and possess a larger kurtosis during the night than the day across all contracts, except for corn. The distributions for best depth and total depth for the day and night sessions are illustrated in Figure 2. Across all futures, the distributions of the best depth.

5.3. Duration

Each of the depth messages updates the first, second, third, fourth, and/or fifth depth level in any combination. Table 9 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"), although it represents less than 30% of all depth updates. In other words, there is a massive amount of depth activity that includes the other levels in the limit order book. For oil, the top change for the depth level indicator is a change to all five levels at once ("11111"). Aitken et al. (2007) uses a unique dataset identifying institutional investors to show that traders provide depth at multiple levels concurrently. Our results also show support for the notion that depth is provided at multiple levels simultaneously, as evidenced by the depth update combinations in Table 9 where depth updates are concurrent at multiple levels. Figure 3 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 percentage of messages that involve the first level of depth and exclude the first level of depth. For the euro and yen futures, the percentage of messages omitting the best depth is slightly larger than fifty percent, whereas for gold and oil futures the percentage of messages not involving the best depth are almost double those involving the best depth. Figure 3 illustrates that a large proportion of depth message traffic does not involve the best level. This result is similar to Cao, Hansch, and Wang (2008) who also document substantial depth activity beyond the top of the book. However, we find that over 50% of the depth updates take place beyond the best level, whereas Cao, Hansch, and Wong (2008) find that approximately 37% of the limit orders are placed outside the best level for equities on the Australian Securities Exchange (ASX). Alternatively, Fong and Liu (2010) find that depth activity is concentrated near the top of the book.

Table 10 presents the duration results for the day and night periods. This 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 all of the futures, the duration (the time elapsed in seconds between depth message updates) is smaller during the day than during the night. This implies that the depth updates occur more often during the day than the night. This result is similar to Fong and Liu (2010), who find that limit order book revisions/cancellations are lower during periods when the monitoring cost is higher. During the day the smallest duration occurs for oil (0.07) and the largest for corn (0.27). The futures contracts examined here show a much smaller duration compared to Ranaldo (2004), who finds that the duration between orders in the limit order book for stocks on the Swiss Stock Exchange ranges from 14.0 to 121.2 seconds. At 0.16 seconds, the euro has the smallest duration and at 5.24 seconds corn has the largest duration during the night. The euro is traded world-wide and

therefore possesses a more consistent demand over the 24 hour cycle, resulting in a short duration between updates during the U.S. night session. Alternatively, corn is primarily a domestic contract which mostly trades during the regular U.S. day hours and therefore possesses a large duration at 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 we do not find evidence to support a difference in duration between the day and night sessions.

5.4. Symmetry

Figure 4 presents the shape of the limit order book for each futures contract. For instance, oil and gold futures both show an increase in depth at each level away from the best level. In other words, more depth is available to transact at each subsequent depth level along the limit order book. This result is similar to Biais, Hillion, and Spatt (1995) and Cao, Hansch, and Wong (2009), who find a monotonic *increase* in the size of the depth at each individual depth level for stocks on the Paris Bourse and ASX, respectively. However, the shape of the limit order book for the other futures contracts provide a strikingly different pattern. The T-note and corn futures show an increase in depth at levels one through three, a decrease at level four, and an increase at level five. The euro futures increases between levels one and four but decreases at the fifth depth level. The yen futures displays an increase in depth over the first three levels and then a decrease over the last two depth levels. Overall, our limit order book shapes vary from those found in Niemayer and Sandas (1993), where the depth is larger near the best level and smaller further out along the limit order book.

Table 11 shows the results for the symmetry of the depth levels. During the day period, the T-note, euro, yen, and gold futures are symmetric between the bid and ask sides of the book

at each depth level. The corn future is only symmetric at the first level and oil futures at levels three, four, and five. 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. When a future is symmetric at a given level, this shows that no statistical difference exists between the bid and ask sides of the book at that level. In related literature, Cao, Hansch, and Wang (2009) document an imbalance in the limit order book beyond the first few levels for stocks on the ASX. They also show that a larger asymmetry in the book hold greater explanatory power in relation to future short-term returns. In addition, Niemayer and Sandas (1993) show that the limit order book for stocks on the Stockholm Stock Exchange are not symmetrical. Ranaldo (2004) also provides additional evidence against symmetry in the limit order book.

5.5. Equality

Table 12 presents the results for the equality of depth for the day and night sessions. The table shows 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 the equality of all depths is consistent with Niemayer and Sandas (1993), Biais, Hillion, and Spatt (1995), and Al-Suhaibani and Kryzanowski (2000). 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 12 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 the equality of all depth levels when the first depth level is excluded. The implication is that depth is

allocated differently in the electronic futures markets relative to the equity markets.

Table 13 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. Consequently, comparing any two of the five depth levels at one time shows that depth is not equal for different depth levels. Exceptions occur for the T-note and corn futures.

6. Conclusions

This study documents the characteristics and allocation of depth in the U.S. electronic futures markets using a five-deep limit order book. We show that depth during the day is larger than depth during the night and document the presence of a large proportion of total depth beyond the best level. Our analysis also shows that depth is updated faster during the day than at night. We find that the limit order book shape is different for different futures contracts. This implies that market participants engage in different trading and depth allocation strategies across the different futures contracts. Moreover, the equality and the symmetry characteristics that we obtain for U.S. electronic futures markets diverge from past research. In particular, we find symmetry between the bid and ask sides of the limit order book, but not equality across different levels of depth. Past research (on stocks) finds asymmetric limit order books and equality *after* excluding one depth level. If prior research on the informativeness of the limit order book depth is based on the shape and characteristics of the book depth, then an interesting research question is to examine whether different conclusions would be drawn for U.S. electronic futures markets.

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Contracts and Dates

This table presents contract information concerning the futures contracts used in this study, including the designated electronic ticker symbols for the contracts employed in this study. The dates represent the time span of available data. Days shows the number of trade dates available for each contract after the removal of missing data. The encoded file size is the size of the encoded RLC formatted datasets and decoded file size is the decoded database we employ. Depth messages reflect the number of depth updates that occur during our sample period.

Contract	Ticker	Datas	Dava	Encoded File	e Decoded File	eDepth
Contract	Symbol	Dates	Days	Size	Size	Messages
T-note	ZN	01/28/2008 – 03/13/2009	214	58.10 GB	37.50 GB	174,118,480
Corn	ZC	01/14/2008 – 03/20/2009	285	133.00 GB	6.34 GB	30,420,858
Oil	CL	01/02/2008 – 04/17/2009	327	1.09 TB	62.60 GB	308,238,184
Euro	6E	01/03/2008 – 10/02/2009	398	144.00 GB	103.00 GB	495,558,768
Yen	6J	01/03/2008 – 10/02/2009	441	95.40 GB	67.40 GB	325,195,385
Gold	GC	01/02/2008 – 04/17/2009	307	365.00 GB	31.20 GB	152,281,837

Trade Activity and Hours

Panel A presents a summary of the overall trade activity for 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 for 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. In panel B, we list the hours for the day trading period and the night trading period. The day trading time represents electronic trading during the time when floor trading is also open. The night trading time is the hours beyond the open outcry time.

Panel A: Trade Activity		
Contract	Volume	Electronic
T-note	189,852,019	95.18%
Corn	50,948,804	87.69%
Oil	137,428,494	92.25%
Euro	54,393,644	99.04%
Yen	22,749,569	98.15%
Gold	35,139,541	89.74%
Panel B: Trading Hours		
Futures Contract	Day (Open Outcry)	Night (Non-Open Outcry)
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

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	One-half of one
			of 1/32 of a point	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	\$0.01 per barrel
			cents per barrel	
Euro	CME	125,000 euros	U.S. dollars and	\$.0001 per euro
			cents	increments
Yen	CME	12,500,000 yen	U.S. dollars and	\$.000001 per
			cents	Japanese yen
				increments
Gold	COMMEX	100 troy ounces	U.S. dollars and	\$0.10 per troy
			cents per troy	ounce
			ounce	

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 the 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. *** identifies significance at the one percent level.

	t statistic	
Panel A: Best Depth		
T-note	-16.81***	
Corn	-22.99***	
Oil	-22.89***	
Euro	-13.79***	
Yen	-08.27***	
Gold	-16.32***	
Panel B: Total Depth		
T-note	-14.14***	
Corn	-29.01***	
Oil	-23.53***	
Euro	-16.14***	
Yen	-10.16***	
Gold	-14.76***	

Individual Depth Level Summary

This table presents the summary statistics for the depth at each depth level on the bid and ask sides of the limit order book. Depth is summarized separately for the day and the night sessions; these results examine five minute intervals.

	Me	an	Med	ian S	Standard I	Deviation	Skew	ness	Kurte	osis	5tl	h	95	th
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Panel A: T-not	e													
Bid Depth 1	404.44	187.59	392.28	147.94	221.62	156.51	0.92	2.75	3.05	23.72	101.61	28.48	777.95	475.81
Bid Depth 2	900.86	395.65	908.83	322.60	488.35	304.12	0.30	1.90	-0.46	14.30	190.13	55.79	1718.80	981.01
Bid Depth 3	951.35	453.34	948.47	374.04	515.71	333.75	0.40	1.20	-0.19	1.90	204.23	67.07	1826.89	1087.75
Bid Depth 4	921.24	469.47	930.39	386.55	505.72	350.06	0.32	1.20	-0.43	1.93	192.41	67.51	1768.59	1145.25
Bid Depth 5	925.73	470.22	950.35	386.09	525.71	354.11	0.22	1.15	-0.63	1.56	162.78	66.49	1776.52	1145.03
Ask Depth 1	400.85	186.92	388.09	148.64	216.01	157.07	0.70	2.74	1.01	19.27	100.35	29.15	775.32	473.11
Ask Depth 2	888.82	388.85	895.56	321.61	476.37	300.19	0.25	1.73	-0.58	8.08	189.62	56.51	1682.89	964.96
Ask Depth 3	935.96	447.28	940.31	371.45	498.03	333.46	0.32	1.30	-0.33	2.69	201.55	68.67	1768.41	1085.93
Ask Depth 4	903.47	462.65	910.08	374.64	492.23	359.49	0.31	1.67	-0.41	6.49	186.62	70.55	1723.20	1131.19
Ask Depth 5	910.88	461.41	929.60	376.07	517.05	355.02	0.24	1.40	-0.58	4.43	158.30	67.02	1751.48	1124.82
Panel B: Corn														
Bid Depth 1	33.69	10.82	28.06	5.92	27.66	17.41	15.55	8.10	554.21	145.94	12.22	1.13	71.11	35.14
Bid Depth 2	62.37	17.67	52.56	9.17	43.13	29.45	4.76	7.17	65.03	90.80	20.71	1.33	131.74	58.83
Bid Depth 3	66.89	20.99	56.79	11.00	45.43	35.18	3.39	6.32	29.54	61.21	20.85	1.50	144.24	69.00
Bid Depth 4	62.92	22.83	52.00	12.00	45.19	38.95	2.95	6.91	22.17	74.86	16.72	1.63	142.88	74.22
Bid Depth 5	63.35	24.35	51.21	13.08	48.86	40.28	3.32	6.88	26.69	76.55	16.22	1.96	148.00	79.00
Ask Depth 1	32.94	12.54	27.44	6.47	28.32	23.71	15.30	9.89	465.47	168.03	12.36	1.21	67.39	41.29
Ask Depth 2	59.41	20.45	50.39	9.71	39.35	43.71	4.27	9.41	48.56	124.49	21.19	1.33	126.33	66.05
Ask Depth 3	62.32	22.86	53.17	11.31	40.77	40.46	3.22	7.63	22.23	96.12	21.13	1.47	132.75	79.12
Ask Depth 4	57.27	24.22	47.59	12.52	41.18	40.18	4.15	7.10	45.38	87.57	17.24	1.67	128.40	83.51
Ask Depth 5	57.70	26.09	47.16	14.00	42.42	38.05	3.62	4.68	33.60	36.23	16.61	1.80	134.06	93.07

	I	Mean	Ν	Iedian	Standar	d Deviation	on Sł	tewness	K	urtosis		5th	9	5th
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Panel C: Oil														
Bid Depth 1	4.85	3.23	4.56	2.51	1.57	2.91	1.12	9.13	2.28	201.79	2.85	1.15	7.77	7.39
Bid Depth 2	7.90	4.42	7.29	3.28	3.27	4.34	1.05	8.44	1.83	204.85	3.77	1.26	14.08	10.99
Bid Depth 3	10.64	5.12	9.56	3.69	5.09	4.98	1.06	5.25	1.23	61.05	4.49	1.36	20.52	13.59
Bid Depth 4	12.91	5.53	11.34	3.94	6.58	5.48	1.05	5.99	0.91	98.83	5.21	1.42	26.11	14.89
Bid Depth 5	14.95	5.92	13.23	4.17	7.37	5.83	0.97	4.74	0.66	51.58	5.97	1.50	29.71	16.23
Ask Depth 1	4.70	3.18	4.44	2.44	1.52	2.82	1.05	7.50	1.97	140.22	2.74	1.12	7.51	7.44
Ask Depth 2	7.54	4.37	6.96	3.18	3.08	4.58	1.11	8.34	2.45	149.55	3.67	1.24	13.30	11.00
Ask Depth 3	10.35	5.13	9.29	3.68	4.91	5.27	1.17	6.96	2.58	117.71	4.43	1.33	19.74	13.60
Ask Depth 4	12.86	5.62	11.27	4.05	6.54	5.52	1.05	4.88	0.85	53.09	5.17	1.42	25.97	15.30
Ask Depth 5	15.11	6.03	13.50	4.27	7.32	5.84	1.00	3.87	0.78	28.59	6.13	1.50	29.88	16.67
Panel D: Euro)													
Bid Depth 1	21.10	13.48	18.95	10.90	11.41	9.37	0.91	2.04	1.29	17.74	6.65	3.57	41.62	31.41
Bid Depth 2	55.56	34.37	51.12	28.13	30.61	23.58	0.54	1.11	-0.30	2.04	15.17	7.57	109.45	78.72
Bid Depth 3	80.39	48.94	76.46	43.55	40.59	29.34	0.30	0.80	-0.87	0.79	24.11	11.87	147.66	101.61
Bid Depth 4	85.18	50.07	79.69	44.47	40.04	28.26	0.32	0.83	-0.82	0.95	29.71	13.79	152.20	101.87
Bid Depth 5	77.57	42.08	72.47	36.69	34.63	23.80	0.37	0.98	-0.64	1.19	29.88	12.36	135.72	86.99
Ask Depth 1	21.00	13.31	18.78	10.82	11.35	9.12	0.94	1.49	1.98	3.65	6.67	3.47	41.44	31.04
Ask Depth 2	55.72	34.13	51.24	27.95	30.83	23.61	0.52	1.14	-0.48	2.81	15.16	7.30	109.74	78.22
Ask Depth 3	80.53	49.22	75.63	43.35	41.00	30.16	0.32	0.85	-0.90	0.99	24.16	11.58	149.13	103.83
Ask Depth 4	85.09	50.22	80.05	44.56	39.83	28.49	0.31	0.83	-0.86	1.00	29.83	13.50	151.58	102.52
Ask Depth 5	78.09	42.05	73.14	36.63	34.96	24.04	0.36	1.10	-0.66	2.86	29.71	12.14	136.25	87.23

Table 5 (Continued)

	N	Mean	Ν	Iedian	Standar	d Deviation	on Sl	kewness	K	urtosis		5th	9	5th
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Panel E: Yen														
Bid Depth 1	18.99	13.53	14.97	10.03	12.50	10.71	1.37	2.09	2.91	6.64	5.46	3.55	43.50	35.37
Bid Depth 2	50.22	35.23	37.05	24.23	35.97	28.55	0.91	1.20	-0.12	1.12	10.55	6.46	119.98	93.33
Bid Depth 3	72.92	46.82	55.69	34.31	48.28	34.00	0.69	0.93	-0.65	0.08	16.25	9.11	161.96	113.48
Bid Depth 4	72.18	44.14	55.93	32.66	43.78	30.74	0.72	0.99	-0.61	0.19	21.70	9.74	154.37	105.11
Bid Depth 5	61.27	38.04	48.98	27.66	35.05	27.06	0.74	0.99	-0.42	0.25	21.07	8.24	125.77	90.41
Ask Depth 1	19.02	13.59	15.02	10.15	12.55	10.72	1.39	2.17	2.91	9.02	5.50	3.57	43.78	35.63
Ask Depth 2	50.47	35.36	37.07	24.44	36.37	28.70	0.98	1.20	0.20	0.90	10.57	6.41	121.39	94.05
Ask Depth 3	71.85	46.60	54.47	33.77	47.33	34.24	0.70	0.95	-0.60	0.09	16.28	9.07	159.00	113.68
Ask Depth 4	71.35	43.80	55.91	32.34	42.51	30.49	0.69	0.97	-0.66	0.18	21.65	9.50	149.78	104.08
Ask Depth 5	61.66	38.05	49.76	27.74	35.46	26.95	0.77	0.98	-0.31	0.23	21.20	8.13	127.94	90.79
Panel F: Gold														
Bid Depth 1	6.21	4.29	5.83	3.60	2.50	2.88	1.14	3.92	2.43	36.39	3.03	1.56	10.75	9.17
Bid Depth 2	10.00	6.05	9.61	4.89	4.74	4.76	1.22	5.61	6.42	105.02	3.93	1.83	18.20	13.75
Bid Depth 3	11.56	7.40	10.98	5.97	5.63	5.79	1.20	4.14	5.59	51.77	4.31	2.02	21.46	17.30
Bid Depth 4	12.22	8.41	11.38	6.75	6.02	6.50	1.22	3.64	3.94	40.97	4.59	2.16	23.02	19.76
Bid Depth 5	12.84	8.99	11.90	7.24	6.29	6.97	1.52	3.70	7.97	34.15	4.90	2.31	23.94	20.98
Ask Depth 1	6.19	4.33	5.80	3.61	2.50	2.93	1.15	3.64	2.46	30.22	3.01	1.56	10.75	9.40
Ask Depth 2	9.98	6.11	9.53	4.89	4.71	4.96	1.01	6.18	2.58	118.12	3.89	1.83	18.15	14.16
Ask Depth 3	11.51	7.52	11.01	6.02	5.57	5.94	1.02	3.45	2.78	26.42	4.23	2.01	21.21	17.86
Ask Depth 4	12.14	8.53	11.36	6.78	5.98	6.79	1.16	3.35	2.78	24.21	4.44	2.17	22.95	20.34
Ask Depth 5	12.75	9.11	11.89	7.21	6.30	7.29	1.30	3.47	3.56	27.83	4.75	2.33	24.06	21.82

Table 5 (Continued)

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 bid and ask sides for that depth 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.

	М	ean	Me	edian	Standard	Deviation	n Skev	wness	Ku	rtosis	5	ith	95	oth
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Panel A: T-note	e													
Level Depth 1	805.29	374.51	807.93	313.38	404.63	277.39	0.35	1.92	-0.10	9.42	210.96	70.50	1469.01	898.53
Level Depth 2	1789.68	784.50	1831.36	661.69	935.03	562.62	0.13	1.31	-0.85	3.59	395.03	131.85	3324.72	1860.96
Level Depth 3	1887.31	900.62	1914.18	764.37	980.61	624.32	0.22	1.03	-0.58	1.05	428.86	159.71	3502.37	2091.59
Level Depth 4	1824.72	932.12	1857.39	785.54	959.91	656.30	0.13	1.09	-0.85	1.34	404.93	169.04	3376.55	2196.13
Level Depth 5	1836.61	931.62	1902.14	787.97	1005.35	654.56	0.06	1.01	-1.01	0.93	346.72	166.37	3414.17	2185.78
Bid Depth	4103.63	1976.27	4209.68	1682.76	2155.98	1366.05	0.13	1.00	-0.89	0.93	885.39	348.00	7675.23	4591.71
Ask Depth	4039.98	1947.10	4139.78	1650.09	2101.87	1361.68	0.10	1.07	-0.92	1.17	881.00	357.09	7502.04	4572.80
Total Depth	8143.61	3923.36	8394.51	3392.56	4162.99	2613.49	0.02	0.93	-1.04	0.63	1842.43	761.79	14838.96	8896.26
Panel B: Corn														
Level Depth 1	66.63	23.36	57.48	14.93	43.97	30.36	7.99	6.66	154.20	82.35	26.97	4.00	131.25	67.86
Level Depth 2	121.78	38.12	108.20	24.00	66.22	53.49	2.54	6.55	17.79	65.78	47.48	5.58	237.39	111.95
Level Depth 3	129.21	43.85	116.38	29.00	66.32	53.05	1.83	5.01	8.13	41.18	49.62	6.92	247.79	126.57
Level Depth 4	120.19	47.04	107.29	32.00	65.56	55.09	2.04	4.99	11.19	41.41	42.62	7.29	237.24	133.45
Level Depth 5	121.05	50.44	107.04	35.20	67.04	54.57	2.07	4.29	10.94	31.02	42.92	8.40	241.96	140.50
Bid Depth	289.22	96.65	251.40	65.80	167.60	105.50	1.72	3.73	5.09	20.47	98.65	16.71	598.15	279.06
Ask Depth	269.65	106.16	237.12	70.93	147.52	119.71	1.78	3.96	5.40	24.15	102.83	17.30	547.68	315.16
Total Depth	558.87	202.80	515.92	160.67	253.75	157.85	0.98	2.84	1.14	11.73	228.52	60.67	1036.09	489.50

	Μ	lean	M	edian	Standard	l Deviatio	n Ske	wness	Ku	rtosis	4	5th	95	5th
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Panel C: Oil														
Level Depth 1	9.55	6.41	9.09	5.35	2.76	4.32	0.83	5.41	0.76	72.84	5.91	2.67	14.72	13.34
Level Depth 2	15.45	8.79	14.39	7.00	5.81	6.75	0.80	5.11	0.52	65.58	7.87	3.07	26.38	20.27
Level Depth 3	21.00	10.25	19.04	7.97	9.29	7.98	0.87	3.73	0.44	32.12	9.43	3.31	38.84	24.93
Level Depth 4	25.78	11.15	22.64	8.64	12.43	8.74	0.95	3.36	0.45	25.10	10.98	3.50	50.94	27.56
Level Depth 5	30.06	11.95	26.93	9.12	13.88	9.35	0.88	2.85	0.33	14.77	12.76	3.71	58.26	30.11
Bid Depth	51.26	24.22	46.61	18.81	22.52	18.24	0.88	3.01	0.40	16.37	23.36	8.17	95.42	59.09
Ask Depth	50.58	24.33	46.01	18.76	22.06	18.59	0.90	2.85	0.49	13.62	23.21	8.04	94.20	60.27
Total Depth	101.83	48.55	92.79	39.92	42.33	30.19	0.80	2.15	0.08	6.65	48.53	19.15	185.91	108.33
Panel D: Euro														
Level Depth 1	42.10	26.79	38.26	22.38	21.65	16.95	0.61	1.33	-0.24	3.44	13.68	8.15	81.08	59.98
Level Depth 2	111.28	68.50	103.64	57.01	59.90	45.09	0.43	0.99	-0.74	0.88	31.48	17.13	216.39	152.44
Level Depth 3	160.93	98.16	153.22	87.54	79.99	57.59	0.23	0.69	-1.10	-0.08	49.71	25.07	291.81	201.55
Level Depth 4	170.27	100.28	159.85	89.70	78.13	54.79	0.23	0.69	-1.08	-0.08	61.14	28.71	298.25	200.72
Level Depth 5	155.67	84.13	146.27	73.52	67.53	45.50	0.23	0.84	-1.03	0.42	60.82	26.29	266.26	170.04
Bid Depth	319.81	188.93	299.83	167.24	150.84	106.41	0.26	0.78	-1.06	0.18	111.15	55.26	570.67	385.05
Ask Depth	320.44	188.93	300.68	165.97	151.55	107.58	0.26	0.79	-1.07	0.21	111.13	54.06	576.26	386.33
Total Depth	640.25	377.86	601.37	334.65	298.48	210.18	0.21	0.73	-1.17	-0.06	226.45	111.65	1135.22	764.11

Table 6 (Continued)

	M	lean	M	edian	Standard	l Deviatio	n Ske	ewness	Kı	ırtosis	:	5th	9:	5th
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Panel E: Yen														
Level Depth 1	38.01	27.11	30.14	20.59	23.80	19.39	1.05	1.67	0.62	4.06	11.33	8.31	85.43	67.78
Level Depth 2	100.68	70.60	74.04	48.33	70.83	55.53	0.85	1.12	-0.38	0.48	21.72	14.87	237.92	184.08
Level Depth 3	144.77	93.42	109.52	67.27	94.58	67.19	0.65	0.91	-0.82	-0.16	33.53	19.62	319.35	225.11
Level Depth 4	143.53	87.94	111.38	64.29	85.38	60.13	0.67	0.95	-0.77	-0.05	44.15	20.65	302.47	207.30
Level Depth 5	122.93	76.10	98.22	55.01	69.29	52.72	0.68	0.91	-0.67	-0.17	43.57	17.92	252.14	177.85
Bid Depth	275.57	177.76	211.16	126.88	170.06	124.06	0.68	0.96	-0.79	-0.05	80.15	43.47	595.85	424.28
Ask Depth	274.35	177.41	209.96	126.38	168.55	124.07	0.69	0.97	-0.75	-0.03	79.83	42.91	591.31	425.17
Total Depth	549.92	355.17	419.56	251.34	336.86	246.49	0.67	0.96	-0.84	-0.11	161.77	88.73	1188.86	846.51
Panel F: Gold														
Level Depth 1	12.40	8.62	11.85	7.59	4.52	4.53	0.77	2.30	0.72	11.95	6.42	3.68	20.48	16.88
Level Depth 2	19.98	12.17	19.65	10.49	8.61	7.43	0.61	3.51	0.61	40.74	8.43	4.49	34.41	25.13
Level Depth 3	23.08	14.92	22.64	12.94	9.98	9.05	0.52	2.19	0.23	12.95	9.30	5.01	39.90	31.26
Level Depth 4	24.36	16.94	23.52	14.76	10.42	10.27	0.59	1.96	0.25	10.10	9.90	5.49	42.55	35.44
Level Depth 5	25.59	18.10	24.68	15.67	10.68	11.00	0.67	2.07	0.91	10.35	10.57	5.90	44.24	37.77
Bid Depth	52.82	35.15	51.07	30.13	22.78	21.33	0.66	1.91	0.40	6.91	21.94	11.93	92.86	74.34
Ask Depth	52.57	35.59	50.97	30.39	22.74	22.20	0.69	2.02	0.52	7.34	21.46	11.89	92.44	76.58
Total Depth	105.40	70.74	104.48	64.22	41.22	34.80	0.30	1.11	-0.71	1.72	46.50	27.94	175.19	135.64

Table 6 (Continued)

Depth Order 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.

	Μ	lean	Me	edian	Standard	l Deviatio	n Ske	wness	Ku	rtosis	5	5th	95	5th
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Panel A: T-note														
Best Depth Orders	57.59	20.50	56.03	16.40	21.21	13.52	0.44	1.66	0.23	4.09	26.18	6.34	95.27	47.34
Total Depth Orders	491.83	203.88	503.14	177.56	174.66	114.53	-0.09	1.10	-0.73	1.42	208.46	64.44	767.87	420.92
Best Depth/Best Orders	13.77	19.58	13.42	17.04	4.88	11.29	0.85	3.05	2.83	24.11	6.31	7.60	22.17	39.61
Total Depth/Total Orders	15.78	18.79	16.30	17.89	5.00	7.06	0.15	1.32	0.13	6.49	7.59	8.94	24.14	31.47
Panel B: Corn														
Best Depth Orders	13.56	4.86	12.51	4.00	5.38	4.85	1.72	13.47	12.36	283.12	6.96	2.08	23.61	9.44
Total Depth Orders	94.53	36.23	87.68	31.66	35.97	23.72	0.76	5.56	0.32	46.75	46.94	17.08	161.77	64.62
Best Depth/Best Orders	5.16	4.93	4.54	3.54	2.40	5.04	3.52	5.71	44.99	69.90	2.69	1.29	9.29	12.90
Total Depth/Total Orders	6.16	5.63	5.54	4.86	2.51	3.00	1.83	2.52	10.27	10.62	3.29	2.64	10.84	10.96
Panel C: Oil														
Best Depth Orders	5.07	3.08	4.84	2.88	1.36	0.86	1.00	2.35	1.28	18.34	3.33	2.11	7.70	4.73
Total Depth Orders	56.94	23.28	53.43	20.05	22.58	11.34	0.53	2.43	-0.54	8.42	27.18	12.85	98.44	44.76
Best Depth/Best Orders	1.93	2.11	1.86	1.74	0.47	1.39	1.01	6.22	1.56	90.21	1.32	1.05	2.81	4.26
Total Depth/Total Orders	1.81	2.11	1.77	1.83	0.36	1.01	0.96	3.10	1.86	17.94	1.32	1.20	2.45	3.97

Table 7 (Continued)

	Μ	lean	Me	edian	Standard	l Deviation	n Ske	wness	Ku	rtosis		5th	9:	5th
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Panel D: Euro														
Best Depth Orders	18.93	11.39	17.82	9.08	8.51	7.32	0.83	1.29	0.61	1.49	7.19	3.70	35.58	26.19
Total Depth Orders	188.10	103.12	181.30	84.74	80.26	64.06	0.66	1.30	0.37	1.72	73.20	31.16	341.85	231.78
Best Depth/Best Orders	2.26	2.52	1.97	2.20	0.87	1.28	0.98	2.70	1.08	16.61	1.29	1.26	3.80	4.79
Total Depth/Total Orders	3.47	4.00	3.25	3.73	1.09	1.56	0.69	1.17	0.02	3.10	2.04	1.97	5.44	7.03
Panel E: Yen														
Best Depth Orders	18.25	10.39	17.42	8.69	8.10	6.49	0.48	1.26	-0.19	1.64	6.46	3.16	32.81	23.43
Total Depth Orders	158.84	86.74	153.75	73.42	68.58	54.51	0.38	1.04	-0.23	0.83	54.96	20.92	280.87	195.15
Best Depth/Best Orders	2.02	2.77	1.86	2.38	0.74	1.57	1.56	2.94	9.91	19.27	1.18	1.24	3.29	5.62
Total Depth/Total Orders	3.39	4.35	3.07	4.01	1.27	1.96	0.74	1.23	0.98	2.40	1.80	1.91	5.65	8.02
Panel F: Gold														
Best Depth Orders	5.73	3.60	5.69	3.45	1.30	0.94	0.35	1.08	-0.22	2.66	3.83	2.35	7.89	5.30
Total Depth Orders	50.13	26.36	49.71	25.03	15.97	8.96	0.13	0.67	-0.87	0.15	25.58	14.30	75.81	42.47
Best Depth/Best Orders	2.17	2.44	2.09	2.16	0.54	1.21	1.25	3.70	3.42	30.02	1.46	1.28	3.16	4.48
Total Depth/Total Orders	2.09	2.67	2.02	2.47	0.47	0.98	1.14	2.54	2.81	16.81	1.46	1.57	2.95	4.42

Comparison of Moments

This table presents a comparison of statistical moments across the futures contracts. The panels compare the moments for the best depth and total depth for both the day and the night sessions.

	Coefficient of Variation	Skewness	Kurtosis
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 Nigh	t		
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

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" represent 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	Flags	Count	Percent	Flags	Count Percent		
T-Note Futures			Corn Futu	ires		Oil Futures			
10000	45,062,577	25.88	10000	8,943,324	29.40	11111	44,098,03614.31		
01000	28,573,022	16.41	01000	3,977,845	13.08	00001	41,652,50713.51		
00100	14,248,311	8.18	01100	3,071,837	10.10	00010	29,566,1089.59		
10100	11,149,758	6.40	11111	2,441,434	8.03	01000	26,524,8598.61		
01100	10,171,893	5.84	11000	2,329,984	7.66	00100	26,385,9958.56		
11000	8,203,883	4.71	00100	2,086,886	6.86	10000	25,766,3138.36		
00001	8,014,641	4.60	00001	1,502,356	4.94	00011	19,389,9746.29		
00110	7,807,299	4.48	00110	1,383,515	4.55	00110	12,913,8594.19		
00010	7,414,234	4.26	00010	1,350,163	4.44	01111	11,238,1253.65		
10010	6,152,044	3.53	00011	742,024	2.44	00111	9,651,001 3.13		
00011	5,652,230	3.25	10100	621,768	2.04	01100	8,665,130 2.81		
11111	3,917,541	2.25	01010	461,051	1.52	00101	6,369,035 2.07		
11100	3,004,626	1.73	11100	304,271	1.00	11000	5,233,053 1.70		
10001	2,305,573	1.32	00101	176,744	0.58	01010	4,761,892 1.54		
01010	1,890,444	1.09	01111	156,833	0.52	01001	3,812,907 1.24		
Other	10,550,404	6.00	Other	870,823	3.00	Other	28,664,9269.00		
Euro Fut	ures		Yen Futur	res		Gold Futi	ıres		
10000	122,101,492	224.64	10000	78,236,054	424.06	10000	26,154,57817.18		
01000	68,624,115	13.85	01000	42,819,830)13.17	00001	23,317,48115.31		
00100	64,526,176	13.02	00100	41,319,047	712.71	01000	20,249,46413.30		
00010	53,161,068	10.73	00010	33,326,574	410.25	11111	16,673,95010.95		
00001	44,810,800	9.04	00001	26,112,074	48.03	00100	16,114,51910.58		
10001	38,964,371	7.86	10010	24,230,737	77.45	00010	13,208,5128.67		
11111	26,331,667	5.31	11111	20,233,574	46.22	00011	8,925,438 5.86		
00110	14,029,472	2.83	10001	14,413,108	34.43	00110	4,972,843 3.27		
01100	11,695,685	2.36	00110	6,700,092	2.06	11000	3,885,572 2.55		
10010	11,234,824	2.27	01100	6,597,410	2.03	01100	3,644,971 2.39		
00011	9,854,904	1.99	10100	6,367,980	1.96	01111	2,884,057 1.89		
10100	7,533,604	1.52	01001	4,974,494	1.53	00111	2,257,822 1.48		
11000	5,603,858	1.13	00011	4,549,918	1.40	00101	1,545,208 1.01		
01010	2,522,784	0.51	11000	3,418,166	1.05	10100	1,497,178 0.98		
01001	2,370,842	0.48	01010	1,932,193	0.59	01010	1,447,344 0.95		
Other	10,284,333	2.00	Other	9,964,134	3.00	Other	5,502,900 4.00		

Day and Night Duration

This table presents results for mean duration between depth updates during the day and the night periods and the difference in duration. The duration is calculated as the amount of time in seconds that elapses between depth message updates. *** illustrates significance at the one percent level.

Futures Contract	Day	Night	t statistic	
T-note	0.09	0.36	08.91***	
Corn	0.27	5.24	16.05***	
Oil	0.07	0.31	10.38***	
Euro	0.08	0.16	0.92	
Yen	0.12	0.22	1.07	
Gold	0.14	0.43	3.69***	

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 periods.

	Day	Night	
	t statistic	t statistic	
Panel A: T-note			
Level 1	-0.22	-0.08	
Level 2	-0.29	-0.36	
Level 3	-0.35	-0.27	
Level 4	-0.41	-0.27	
Level 5	-0.32	-0.35	
Panel B: Corn			
Level 1	0.10	2.36**	
Level 2	-1.73*	1.74***	
Level 3	-2.50**	1.04	
Level 4	-2.97***	0.77	
Level 5	-3.17***	1.07	
Panel C: Oil			
Level 1	-1.78*	-0.93	
Level 2	-1.93*	-0.54	
Level 3	-0.91	0.08	
Level 4	-0.11	0.65	
Level 5	0.32	0.75	
Panel D: Euro			
Level 1	-0.16	-0.40	
Level 2	0.08	-0.18	
Level 3	0.05	0.17	
Level 4	-0.04	0.10	
Level 5	0.24	-0.03	
Panel E: Yen			
Level 1	0.02	0.11	
Level 2	0.10	0.08	
Level 3	-0.33	-0.10	
Level 4	-0.28	-0.18	
Level 5	0.19	0.00	
Panel F: Gold			
Level 1	-0.14	0.48	
Level 2	-0.10	0.48	
Level 3	-0.20	0.68	
Level 4	-0.28	0.60	
Level 5	-0.31	0.57	

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. ***, **, and * represents significance at the one, five, ten percent levels, respectively.

	Day	Night	
	F Value	F Value	
Panel A: T-note			
Equality All Levels	66.85***	64.45***	
Equality Excluding Best	01.26	04.63**	
Panel B: Corn			
Equality All Levels	115.69***	51.87***	
Equality Excluding Best	002.93**	10.51***	
Panel C: Oil			
Equality All Levels	277.04***	210.70***	
Equality Excluding Best	134.01***	068.18***	
Panel D: Euro			
Equality All Levels	312.01***	276.21***	
Equality Excluding Best	061.82***	053.81***	
Panel E: Yen			
Equality All Levels	159.40***	130.45***	
Equality Excluding Best	28.83***	017.17***	
Panel F: Gold			
Equality All Levels	153.66***	223.52***	
Equality Excluding Best	026.71***	085.80***	

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 sessions. ** represents significance at the five percent level.

	Day		Night		Day		Night		Day		Night	
	Diff.	Signif.	Diff.	Signif.	Diff.	Signif.	Diff.	Signif.	Diff.	Signif.	Diff.	Signif.
	T-note				Corn				Oil			
1 - 2	-989.12	**	-405.55	**	-53.478	**	-14.561	**	-5.8911	**	-2.3828	**
1 - 3	-1088.28	**	-520.73	**	-60.523	**	-20.308	**	-11.4449	**	-3.8580	**
1 - 4	-1024.81	**	-551.80	**	-51.531	**	-23.328	**	-16.2294	**	-4.7588	**
1 - 5	-1035.38	**	-551.17	**	-52.444	**	-26.629	**	-20.5228	**	-5.5769	**
2 - 1	989.12	**	405.55	**	53.478	**	14.561	**	5.8911	**	2.3828	**
2 - 3	-99.16		-115.18	**	-7.044		-5.747	**	-5.5538	**	-1.4752	**
2 - 4	-35.69		-146.25	**	1.948		-8.767	**	-10.3383	**	-2.3760	**
2 - 5	-46.26		-145.63	**	1.034		-12.068	**	-14.6317	**	-3.1941	**
3 - 1	1088.28	**	520.73	**	60.523	**	20.308	**	11.4449	**	3.8580	**
3 - 2	99.16		115.18	**	7.044		5.747	**	5.5538	**	1.4752	**
3 - 4	63.48		-31.08		8.992	**	-3.020		-4.7845	**	-0.9008	**
3 - 5	52.90		-30.45		8.078		-6.321	**	-9.0779	**	-1.7189	**
4 - 1	1024.81	**	551.80	**	51.531	**	23.328	**	16.2294	**	4.7588	**
4 - 2	35.69		146.25	**	-1.948		8.767	**	10.3383	**	2.3760	**
4 - 3	-63.48		31.08		-8.992	**	3.020		4.7845	**	0.9008	**
4 - 5	-10.57		0.63		-0.914		-3.301		-4.2934	**	-0.8181	**
5 - 1	1035.38	**	551.17	**	52.444	**	26.629	**	20.5228	**	5.5769	**
5 - 2	46.26		145.63	**	-1.034		12.068	**	14.6317	**	3.1941	**
5 - 3	-52.90		30.45		-8.078		6.321	**	9.0779	**	1.7189	**
5 - 4	10.57		-0.63		0.914		3.301		4.2934	**	0.8181	**

	Day		Night		Ι	Day		light	Ι	Day		Night	
	Diff.	Signif.	Diff.	Signif.	Diff.	Signif.	Diff.	Signif.	Diff.	Signif.	Diff.	Signif.	
	Euro				Yen				Gold				
1 - 2	-69.280	**	-41.783	**	-63.057	**	-43.340	**	-7.6008	**	-3.5517	**	
1 - 3	-118.946	**	-71.417	**	-107.342	**	-66.100	**	-10.6933	**	-6.3120	**	
1 - 4	-128.272	**	-73.504	**	-106.071	**	-60.666	**	-11.9680	**	-8.3170	**	
1 - 5	-113.637	**	-57.360	**	-85.329	**	-48.886	**	-13.2133	**	-9.4924	**	
2 - 1	69.280	**	41.783	**	63.057	**	43.340	**	7.6008	**	3.5517	**	
2 - 3	-49.667	**	-29.634	**	-44.285	**	-22.760	**	-3.0925	**	-2.7603	**	
2 - 4	-58.992	**	-31.722	**	-43.014	**	-17.326	**	-4.3671	**	-4.7653	**	
2 - 5	-44.358	**	-15.577	**	-22.272	**	-5.546		-5.6124	**	-5.9406	**	
3 - 1	118.946	**	71.417	**	107.342	**	66.100	**	10.6933	**	6.3120	**	
3 - 2	49.667	**	29.634	**	44.285	**	22.760	**	3.0925	**	2.7603	**	
3 - 4	-9.325		-2.087		1.271		5.434		-1.2746		-2.0050	**	
3 - 5	5.309		14.058	**	22.013	**	17.214	**	-2.5199	**	-3.1804	**	
4 - 1	128.272	**	73.504	**	106.071	**	60.666	**	11.9680	**	8.3170	**	
4 - 2	58.992	**	31.722	**	43.014	**	17.326	**	4.3671	**	4.7653	**	
4 - 3	9.325		2.087		-1.271		-5.434		1.2746		2.0050	**	
4 - 5	14.634	**	16.145	**	20.742	**	11.780	**	-1.2453		-1.1754	**	
5 - 1	113.637	**	57.360	**	85.329	**	48.886	**	13.2133	**	9.4924	**	
5 - 2	44.358	**	15.577	**	22.272	**	5.546		5.6124	**	5.9406	**	
5 - 3	-5.309		-14.058	**	-22.013	**	-17.214	**	2.5199	**	3.1804	**	
5 - 4	-14.634	**	-16.145	**	-20.742	**	-11.780	**	1.2453		1.1754	**	

Table 13 (Continued)

30000 Corn T-note 1800 1600 25000 1400 20000 1200 Depth 800 Depth 12000 10000 600 400 5000 200 0 0 20:00 22:30 1:00 3:30 6:00 8:30 11:00 13:30 18:00 19:15 20:30 21:45 23:00 0:15 1:30 2:45 4:00 5:15 10:00 11:15 12:30 17:30 Time Time ■ Depth Level 1 ■ Depth Level 2 ■ Depth Level 3 ■ Depth Level 4 ■ Depth Level 5 ■ Depth Level 1 ■ Depth Level 2 ■ Depth Level 3 ■ Depth Level 4 ■ Depth Level 5 350 Oil 2000 Euro 1800 300 1600 250 1400 1400 1200 1000 800 200 Debth Debth Debth 800 600 100 400 50 200 0 0 3:00 5:30 17:00 7.00 20 NS. 30 2 Time Time ■ Depth Level 1 ■ Depth Level 2 ■ Depth Level 3 ■ Depth Level 4 ■ Depth Level 5 ■Depth Level 1 ■Depth Level 2 ■Depth Level 3 ■Depth Level 4 ■Depth Level 5 1800 350 Yen Gold 1600 300 1400 250 1200 Dept 1000 800 **Dept** D 150 600 100 400 50 200 0 17:00 11:45 13:00 17:00 2.00 10:30 11:45 13:00 14:15 15:30 6.30 N.15 5:30 18:15 19:30 20:45 21:00 22:15 0:30 1.45 3:00 æ. .0 Time Time ■ Depth Level 1 ■ Depth Level 2 ■ Depth Level 3 ■ Depth Level 4 ■ Depth Level 5 ■ Depth Level 1 ■ Depth Level 2 ■ Depth Level 3 ■ Depth Level 4 ■ Depth Level 5

Intraday Depth Behavior

This figure presents the intraday behavior of the depth at each level. Each sequential depth level includes the depth at the previous levels. The first depth level is at the bottom (darkest) and the fifth depth level is at the top (lightest).

Distribution of Best Depth (Left) and Total Depth (Right)

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



Figure 2 (Continued)



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.



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 sides.

