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Abstract

The recent 'Financialization' of commodity futures markets, increases in biofuel production, and climate change potentially have imposed profound shifts in the way commodity futures markets operate. This article examines the corn market quote-by-quote to develop metrics on liquidity and transmission of information. The metrics are based on insights derived from sequential trading models on single securities, index futures on a basket of securities, and special features of commodity futures markets. Correlation between quote revisions in nearby and deferred contracts measure information-based activity, and correlations between revisions of the time lagged nearby and deferred maturity measure the speed at which information is transmitted among the different futures maturities. Information-based trading results in near perfect correlation between revisions to bids and offers in nearby and deferred contracts. Within one second, information is fully transmitted from nearby to deferred contracts.

Keywords	market; microstructure; information; electronic trading
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Dear Editors:

I am writing on behalf of myself and my co-authors, Philip Garcia and Teresa Serra, to submit a manuscript titled “What Nearby and Deferred Quotes Tell Us about Linkages and Adjustments to Information” for consideration at the *Journal of Commodity Markets*.

This paper makes a novel contribution to the literature on the microstructure of commodity markets. We measure information-based trading activity using insights from the literature on sequential trading models to arrive on a metric based on the correlation of nearby and deferred corn futures contract quote revisions. Further, we estimate the speed of information transmission by determining the lag length required to achieve zero correlation between lagged nearby and deferred quote revisions.

We find that nearby and deferred contracts revise bids and offers in lock-step when an information event occurs. Further, we find that information is fully transmitted to from nearby to deferred contracts within one second. The implication is that electronic trading has allowed traders to very efficiently convey market information throughout the forward curve.

We are excited to make an early contribution to the new *Journal of Commodity Markets*. We trust that there will be many studies on the microstructure of commodity markets in the future. Thank you in advance for considering ours; we look forward to your response.

Sincerely,

A handwritten signature in black ink that reads 'Mindy L. Mallory'.

Mindy L. Mallory
Assistant Professor

What Nearby and Deferred Quotes Tell Us about Linkages and Adjustments to Information

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What Nearby and Deferred Quotes Tell Us about Linkages and Adjustments to Information

Abstract

The recent ‘Financialization’ of commodity futures markets, increases in bio-fuel production, and climate change potentially have imposed profound shifts in the way commodity futures markets operate. This article examines the corn market quote-by-quote to develop metrics on liquidity and transmission of information. The metrics are based on insights derived from sequential trading models on single securities, index futures on a basket of securities, and special features of commodity futures markets. Correlation between quote revisions in nearby and deferred contracts measure information-based activity, and correlations between revisions of the time lagged nearby and deferred maturity measure the speed at which information is transmitted among the different futures maturities. Information-based trading results in near perfect correlation between revisions to bids and offers in nearby and deferred contracts. Within one second, information is fully transmitted from nearby to deferred contracts.

Key words: market, microstructure, information, electronic trading,

1. Introduction

There has been recent concern about whether and how the ‘Financialization of Commodity Markets’ has impacted market efficiency and efficacy in

4 the traditional roles of risk mitigation, coordinating production, and coor-
5 dinating consumption through time (S. H. Irwin and Sanders 2011; Cheng
6 and Xiong 2013; S. H. Irwin and Sanders 2012; Henderson, Pearson, and
7 Wang 2015). Further, the recent increase in the production of biofuel from
8 food commodities and volatile crude oil prices has changed the relationship
9 between food and energy commodities (Serra and Zilberman 2013; M. L.
10 Mallory, Irwin, and Hayes 2012; Gardebroek and Hernandez 2013; Vacha et
11 al. 2013; Avalos 2014; Trujillo-Barrera et al. 2012). Additionally, climate
12 change, rising demand for agricultural commodities, and volatile inventories
13 and exchange rates have imposed structural changes in commodity markets
14 (Balcombe, Prakash, and others 2011; Gilbert and Morgan 2010; A. Prakash,
15 Gilbert, and others 2011).

16 These issues represent potentially profound shifts in the way commodity
17 markets operate, and the articles cited above have considered their impli-
18 cations. However, how these changes affect commodity markets on a tick-
19 by-tick and quote-by-quote basis needs to be considered. Since global price
20 discovery occurs on global futures exchanges for the major food commodities,
21 a detailed consideration of these changes on trading activity, patterns, and
22 consequences is warranted. We use “high frequency data” (time stamped to
23 the second), in order to capture faster price change adjustments taking place
24 after significant technical developments in trading platforms in the second
25 half of the 2000s, characterized by high speed trading.

26 Price analysis can be classified into structural and non-structural studies.
27 While structural models rely on economic theory, non-structural analyses
28 identify empirical regularities in the data. The approach throughout this

29 article is non-structural. We employ this approach primarily because there
30 is scant market microstructure literature developed with the particular char-
31 acteristics of commodity futures markets in mind. In this article, we are
32 motivated to develop initial metrics of information-based activity in com-
33 modity markets. We anticipate this work will lead to future developments in
34 the microstructure of commodity markets literature.

35 Even how to develop simple metrics of information-based activity from
36 standard microstructure models is not obvious because standard models of
37 trading securities are not necessarily directly applicable to commodity futures
38 markets. For example, in commodities futures markets several contracts with
39 different maturities trade in the marketplace, each reacting to information-
40 and liquidity-motivated trades. Each contract responds to information-based
41 shocks because there is a cost to store the physical commodity through time
42 (Working 1948; Working 1949; Brennan 1958). Further, each contract ma-
43 turity attracts different levels of liquidity, and it is not known what impact
44 a lack of liquidity has on information transmission up the forward curve.

45 The metrics we develop in this article on liquidity and transmission of
46 information are based on insights we combined from the sequential trading
47 models on single securities, index futures based on a basket of securities,
48 and some of the features of commodity futures markets described in the
49 preceding paragraph. Using the standard sequential trading result that quote
50 revisions only occur if liquidity providers have updated their beliefs about
51 the value of the security after observing order flows, the correlation between
52 quote revisions in nearby and deferred contracts can be used to measure
53 information-based activity, and correlations between revisions of the time

54 lagged nearby and deferred maturity can be used to measure the speed at
55 which information is transmitted among the different futures maturities. This
56 metric is sensible in commodity futures markets but not in a market for a
57 single security, because futures markets have multiple maturity contracts that
58 should respond to information in a very similar and predictable way.

59 Garcia and Leuthold (1992) examined how USDA announcements are
60 transmitted in nearby and deferred contracts. Using daily price observations
61 and USDA announcement dates, they observe that deferred futures responses
62 are similar to nearby harvest futures, but the information effect is somewhat
63 smaller. Information appears to affect prices over a horizon of at least five
64 days. Informatively, they call for closer examination of intra-day data to
65 develop a more comprehensive understanding of price behavior. In contrast
66 to the results found by Garcia and Leuthold, we find information is fully
67 transmitted within one second, reflecting a market that is highly efficient
68 in transmitting information up the forward curve from nearby to distant
69 contract maturities.

70 The remainder of the article is organized as follows. First, we provide a
71 background of the sequential trading and index futures microstructure litera-
72 ture and describe the conceptual framework that motivates our interpretation
73 of correlations of quote revisions as a metric of information-based activity.
74 Next we describe the data and report the results of our analysis. Finally, we
75 offer concluding remarks.

76 2. Literature Review

77 The literature on how information affects liquidity in securities markets
78 is long and rich.¹ Bagehot (1971) is regarded as the first to demonstrate that
79 a bid-ask spread (BAS) arises when asymmetric information is present even
80 if inventory and transactions costs are assumed to be zero. Copeland and
81 Galai (1983) build on Bagehot’s work by assuming that a specific proportion
82 of traders are informed. Knowing this, the market maker adjusts his quoted
83 bids and offers to maximize expected profit. Copeland and Galai’s model,
84 however, does not account for the fact that the trades themselves can reveal
85 information about whether or not traders are informed. Glosten and Milgrom
86 (1985) formalize this concept and develop a model where the market maker
87 adjusts his beliefs based on the trades that occur. The market maker knows
88 that at least some of the traders are informed so sell orders revise the market
89 maker’s belief downward about the value of the security and buy orders revise
90 his belief upward. They show that the spread is increasing in the proportion
91 of informed traders, and there is a point at which too many informed traders
92 require the market maker to set the spread so wide, that trade does not
93 occur and the market halts (an example of the famous “Market for Lemons”
94 described by Akerlof (1970)).

95 Easley and O’Hara (1987) and Easley and O’Hara (1992) incorporate
96 trade size and its effect to a model similar to Glosten and Milgrom. A
97 market maker must set breakeven bid and offer quotes knowing that he faces

¹The interested reader can refer to O’Hara (1995) for an excellent and detailed overview of the evolution of this literature.

98 a certain proportion of informed traders who only trade if they receive a
 99 signal that an information event has occurred, and a certain proportion of
 100 uninformed traders who do not receive an information signal but occasionally
 101 need to trade for liquidity reasons. Both informed and uninformed traders
 102 can choose between a large and small block trading size. This model setup
 103 leads to two types of equilibria: a separating equilibrium where informed
 104 traders only trade in large quantities and a pooling equilibria where informed
 105 traders may trade both large and small quantities. This model setup of
 106 information uncertainty and asymmetric information leads to the market
 107 maker updating his beliefs about the value of the security (and therefore his
 108 quotes) based on the order flow he observes in the market. For example, in
 109 a separating equilibrium a large trading block causes the market maker to
 110 revise upward his expectation that an information event has occurred (since
 111 informed traders do not transact at small sizes). This contrasts with the
 112 pooling equilibrium where informed traders place small orders to prevent
 113 the market maker from updating his beliefs that an information event has
 114 occurred.

115 Hasbrouck (2006) provides an overview of how Easley, Hvidkjaer, and
 116 O'Hara (2002) and Easley, Kiefer, and O'Hara (1997) use the Easley and
 117 O'Hara models of informed trading to develop a measure of the probability
 118 of informed trading (PIN). This measure, though, is estimated solely based
 119 on the sequence of order arrivals, where a trade is labeled as buyer initiated if
 120 the trade occurs above the midpoint of the quoted spread and seller initiated
 121 if the trade occurs below the midpoint of the quoted spread. Numerous
 122 studies have documented that there may be problems with downward bias

123 in the estimated PIN (Yan and Zhang 2012; Vega 2006; Boehmer, Grammig,
124 and Theissen 2007) and estimating information-based trading in this way
125 ignores some aspects of futures markets discussed above that are not present
126 in securities markets. For these reasons we seek an alternative to the PIN
127 measure of information-based trading in commodity futures.

128 To our knowledge, there are no market microstructure models that ex-
129 plicitly take into account the features of commodity futures markets. The
130 closest models come from work on index futures that cover a basket of secu-
131 rities. Most prominent is the work by Kumar and Seppi (1994) who assume
132 N different non-dividend paying securities and an index futures contract on
133 a buy-and-hold portfolio of a subset of these stocks. In Kumar and Seppi's
134 model, specialists in the cash market observe a signal, and floor traders
135 of the futures index observe a signal about the value of the index but not
136 the individual securities. A key feature they build into the model is a lag
137 in the information transmittal between the cash and futures markets be-
138 cause specialists only observe order flows from their own market, and not
139 the other. This lag in information transmittal allows for arbitrageurs, who
140 possess faster telecommunication technologies, to learn from transactions in
141 both markets and make profitable trades in the cash and futures markets.
142 These arbitrageurs are analogous to spread traders who trade in both nearby
143 and deferred futures contracts hoping to profit on relative price movements.

144 There are some important distinctions between the arbitrageurs as pro-
145 posed in the Kumar and Seppi model and spread traders in a futures market.
146 Namely, the basis between a composite of cash security prices and the price
147 of a futures index of the same basket should behave in very predictable

ways (the basis, in theory, should only vary with interest rates and expected changes in dividend yields if information is symmetric). In contrast, the spread between the prices of two commodity futures contracts with different maturities depends on many more uncertain structural variables: e.g., domestic and international consumption, exchange rates, production or distribution bottlenecks, or weather. The arbitrageurs in Kumar and Seppi’s model need only to wait for others in the marketplace to learn to profit. The futures market spread trader entertains much more risk in betting on relative price changes between two futures maturities.

In the next section we draw insights from the sequential trading models described above to generate empirical predictions about the correlations between revisions to bids and offers of nearby and deferred maturity commodity futures contracts.

3. Conceptual Framework

In this section we develop a conceptual framework for how the role of liquidity-based activity versus information-based activity should affect quote revisions in a commodity futures market. Using insights from the Easley and O’Hara models, along with features of commodity futures markets, we generate empirical predictions about the correlations between revisions to quotes in the nearby and deferred maturity commodity futures contracts.

First, consider an absence of information. In the Easley and O’Hara sequential trader models, the market maker revises his quotes only when he updates his belief that the value of the security has changed. Therefore, we interpret no changes in revisions to bids (offers) as indicative of no infor-

172 mation having arrived to the market. Any transactions that occur at these
173 prices, the market maker believes are conducted by uninformed traders de-
174 manding liquidity.

175 Conversely, when we observe revisions to the bid or offer, we can infer
176 that the market maker from the Easley and O'Hara models has updated
177 beliefs about information arrival to the market based on past order flows.
178 These revisions to the bid and offer we interpret as indicative of information
179 arriving to the market.

180 Now we discuss features of futures markets that we can utilize when con-
181 sidering revisions to nearby and deferred contract quotes. First, in actively
182 traded commodity futures markets there is no market maker, but there are
183 entities who actively supply liquidity to the market under a variety of mo-
184 tives. Since the Easley and O'Hara models consider a competitive market
185 maker, it is irrelevant whether there is one market maker in the traditional
186 sense or a large number of traders providing liquidity. Second, when market
187 makers revise their beliefs that an information event has arrived to the mar-
188 ket, they know it affects futures contracts of all maturities so quotes must be
189 revised in all contracts.

190 This should induce a high degree of correlation between bid and offer
191 revisions when an information event arrives. Further, one market maker
192 would revise bids and offers on futures contracts of all maturities at the same
193 time they update beliefs about an information event having occurred. As a
194 practical matter, many independent traders provide liquidity to the market
195 at any given time, so it is not clear that the Bayesian updating described in
196 the Easley and O'Hara models will happen in all maturities simultaneously.

197 Therefore, it is of interest to consider the relationship between revisions to
198 quotes in the nearby contract at different time lags) and revisions to quotes
199 in deferred maturity contracts.

200 4. Data

201 The data used in this analysis come from the CME Group's Top of
202 Book (BBO) database for Globex corn futures quotes and transactions from
203 01/14/2008-11/4/2011. The data contain the best bid, bid size, best offer,
204 offer size, last trade price, and last trade size of the order book for each active
205 futures contract, time-stamped to the second.

206 Table 1 shows the first ten entries to our data after manipulating the
207 raw BBO data set from CME Group to display the entire top of the book
208 on one line with the appropriate time stamp. The first column is the time-
209 stamp, the second column is the trade sequence number, which the CME
210 Group gives to individual trades to identify separate orders that arrive on the
211 same second. The third column, SYMBOL, identifies which futures maturity
212 the observation represents. In this case, 1003 stands for March 2010, with
213 the first two characters representing the year and the second two characters
214 representing the month. The fourth column, OFRSIZ, is the number of
215 contracts quoted at the best offer price. The fifth column, OFR, is the best
216 offered price. The sixth column, BIDSIZ, is the number of contracts quoted
217 at the best bid price; the last column, BID, is the best bid price. For each date
218 in our sample, we consider the first to mature (nearby), one, two, and three
219 contracts deferred. We define the nearby contract to be the next contract to
220 expire unless the date was after the 20th of the month prior to expiration.

221 Then we roll the nearby to the next to expire contract. We rolled the series
222 on the 20th to avoid decreasing volume as the contract neared the delivery
223 period. We also excluded the September futures contract from our analysis
224 because of low trading volume.²

225 Figure 1 displays average transaction price per day, number of revisions
226 to the ask, number of revisions to the bid, and number of transactions — all
227 in the nearby contract. The first panel demonstrates that the time period
228 examined was characterized by volatility, uncertainty, and rapid increases in
229 prices in the beginning and end of the sample. Note that prices increased to
230 a peak of nearly \$8.00 per bushel in 2008, a time a time that saw a broad
231 class of commodity markets exhibiting similar rapid price increases. The
232 prices in the last half of 2008 were in sharp decline as commodity markets
233 were influenced by the financial meltdown that led to the Great Recession
234 (Caballero, Farhi, and Gourinchas 2008).

235 Then a relatively stable period from 2009 and 2010 saw prices within a
236 relatively tight range of \$3.00 to \$4.50 per bushel. In the final year of the
237 sample, uncertainty and rapid price increases reigned again as worries about
238 a smaller than anticipated crop yield and small ending stocks drove prices
239 to nearly \$8.00 per bushel. The number of transactions per day, depicted in
240 the bottom panel, appears to stay within a fairly stable band throughout the
241 sample period – with perhaps an uptrend during the price spike of 2008 and
242 a slight upward trend toward the end of the sample.

²September experiences low trading volumes because deliveries on this contract sometimes (but not usually) can come from early new crop harvest, making its price relative to the traditional new crop contract, December, hard to predict.

243 The second and third panel display the number of revisions to the best
 244 ask and best bid, respectively. The number of quote revisions is fairly stable
 245 within a band of about 25,000 to 50,000 revisions from 2008 to mid 2010.
 246 The exception being a brief period in late 2008 when the market bottomed
 247 after a dramatic fall from a high that summer of nearly \$8.00 per bushel.
 248 Starting in the latter period of 2010, a notable increase in the number of
 249 quote revisions, and the volatility of the number of quote revisions can be
 250 observed. While they do not stay within a well-defined band, most days the
 251 number of quote revisions fall within a range of 30,000 to 75,000. Because
 252 this does not appear to coincide with a commensurate increase in the number
 253 of transactions (depicted in the bottom panel of figure 1), one must assume
 254 this is due to an increase in quoting strategies particularly suited to electronic
 255 markets. A noticeable decrease in the number of transactions, and especially
 256 the number of quote revisions is visible during the final weeks of 2008, 2009,
 257 and 2010, corresponding to the Christmas and New Year's holiday.

258 While price levels were volatile, the share of contracts traded on the
 259 CME's electronic trading platform, Globex, had already stabilized to nearly
 260 90% by 2008 (Peterson 2015). So any effects we study should not be related to
 261 trading infrastructure changes that may have occurred during the migration
 262 of volume to the electronic exchange. The data are time-stamped to the
 263 second, but trades and updates to the top of the book routinely occur more
 264 rapidly than once per second. This results in several updates to the top of the
 265 book displaying the same time stamp. This requires us to either aggregate
 266 to the second, or to simulate sub-second time stamps (Hasbrouck 2015; X.
 267 Wang 2014). Since we calculate correlations between updates to the top-of-

268 the book for several contract maturities, simulation would need to preserve
269 the order and timing of within second updates for each respective contract.
270 Since this is virtually impossible and would be subject to error, we aggregate
271 to the second.³

272 Further, we exclude days on which there was a limit price move in any of
273 the contracts, since when prices are locked at the limit, correlations are not
274 meaningful (dates deleted due to limit price moves and the corresponding in-
275 formation events, if known, are as follows: 1/12/2010, revision to a Crop Pro-
276 duction report; 3/31/2011, Prospective Plantings report; 6/30/2011, Planted
277 Acres report; 10/8/2010, World Agricultural Supply and Demand Estimates
278 (WASDE); and 12/9/2010, WASDE). Also, we exclude 4/5/2010, because
279 there was an unusually high number of revisions to the best bid and best
280 offer. Since we were not able to process all of the data for this day in a
281 reasonable amount of computing time, we drop this day from our sample.
282 Additionally, 7/5/2011 was an unusually light trading day after the Fourth
283 of July holiday and resulted in no data for the third to mature contract, so
284 we dropped this day as well.

285 5. Analysis

286 Our analysis considers the correlation of logged changes to quotes in the
287 nearby contract to logged changes to quotes in the deferred (1, 2, and 3
288 maturities). We described, in the Conceptual Framework section, that when
289 information arrives to the market, it should affect the entire forward curve

³We take the last entry on each time-stamp for the aggregation.

290 in the same direction. In other words, information that raises the best bid
291 (offer) in the nearby contract, should raise the best bid (offer) in the deferred
292 contracts as well. Linkages between the nearby and deferred contracts can be
293 measured with simple correlations in the absence of a formal model. While
294 correlation analysis may be influenced by non-normality in high frequency
295 price data, it provides a straightforward and robust procedure to assess the
296 linkages across changes in contracts for the time intervals (described below)
297 that we use to analyze our research questions.

298 We have two primary objectives: 1) calculate the strength of correlations
299 between the order books of the nearby and deferred contracts, and 2) measure
300 (or bound) the time it takes for information to be transmitted from nearby to
301 deferred contracts. To measure the first, we calculate contemporaneous (zero
302 time lag) correlations between the log changes of quotes in the nearby and the
303 deferred contracts. Then, to measure the second, we calculate the correlation
304 between time lagged log changes of quotes of the nearby with log changes of
305 quotes of the deferred contracts. We lag the nearby by one second and ten
306 seconds. The time lagged correlations provide a measure of how long it takes
307 for information to be transmitted from nearby to the deferred contracts.
308 The logic is that if we observe contemporaneous correlation between the
309 nearby and deferred contracts, we can search for the time lag at which we
310 observe the correlation disappear. We conclude that information has been
311 fully transmitted when the time lagged nearby and deferred contract order
312 book revisions become uncorrelated. Conversely, we may observe that there
313 is no contemporaneous correlation, but there is lagged correlation.

314 Since the corn futures contract experiences non-uniform trading volume

315 throughout the day, there may be time of day effects in the strength and
316 rate at which information is transmitted through the futures market. To
317 capture how the speed of information transmission changes throughout the
318 trading day, we divide the day into ten minute intervals starting at 9:30am
319 Central Standard Time, the beginning of the daytime trading session for
320 CBOT corn futures. We calculate the correlations described in detail below
321 for each ten minute interval. Ten minutes was shown to be long enough
322 for market adjustment to take place in Lehecka (2014). This allows us to
323 detect if there are any discernible patterns to the transmission of information
324 over the trading day. Since one correlation is calculated per day per ten
325 minute interval, for every ten minute interval we recover a distribution of
326 correlations.

327 *5.1. Information-Based Trading Activity and Contemporaneous Correlations*
328 *in the Top of the Book*

329 As mentioned, it is common to have multiple revisions to the order book
330 on the same second (and consequently receive the same time-stamp in the
331 data). The converse is also true, however. It is also common for a number of
332 seconds to transpire before the top of the order book is revised - particularly
333 in the middle of the daytime trading session. This results in our variables (i.e.,
334 changes in quotes) containing many zeros. How these zeros are distributed
335 between the contracts is related to the concepts of liquidity-based versus
336 information-based activity discussed in the conceptual framework.

337 To fix ideas, consider the possible outcomes when examining contempora-
338 neous log changes in the top of the book between the nearby and the deferred
339 contracts. There are three possibilities; on any time stamp one of the three

340 situations may occur: 1) neither the nearby nor the deferred has a zero log
341 change in the bid (offer), 2) either the nearby or the deferred has a zero
342 log change in the bid (offer), but not both, or 3) both the nearby and the
343 deferred have a zero log change in the bid (offer).

344 Based on the definition of liquidity-based activity and information-based
345 activity in the conceptual framework, we present a case for interpreting (1)
346 as information-based activity, (2) liquidity-based activity, and (3) liquidity-
347 based activity.⁴

348 The intuition is that if both the nearby and deferred contracts experience
349 a revision in the same direction, they are likely responding to the arrival
350 of information to the marketplace, and best bids (offers) adjust accordingly.
351 This is in contrast to the case where one of the two contracts experiences
352 a revision to the bid (offer) and the other contract has no change. If one
353 contract experiences a revision in the best bid (offer) and the other does not,
354 it is likely that the revision results from a liquidity-based order in traders'
355 efforts to exit their positions.

356 If this intuition is correct, it is informative to consider only time-stamps
357 for which both contracts experienced a revision - that is isolating what we
358 are referring to as information-based activity to case (1) above.

⁴In the third case, no activity at all is observed in the quoted price changes, but quoted quantities may have changed due to new limit orders arriving, limit orders being cancelled, or market orders arriving taking some of the quoted quantities off the book. This is indicative of liquidity-based activity as well.

$$corr_{tI}^{Bid} = \frac{\sum_{i=1}^n (bid_{ti}^N - \overline{bid_t^N}) (bid_{ti}^D - \overline{bid_t^D})}{\sqrt{\sum_{i=1}^n (bid_{ti}^N - \overline{bid_t^N})^2 \sum_{i=1}^n (bid_{ti}^D - \overline{bid_t^D})^2}} \quad (1)$$

such that bid_{ti}^N and $bid_{ti}^D \neq 0$

Equation 1 indicates that we calculate the correlation between the log change of the nearby best bids, bid_{ti}^N , and the log change of the deferred best bids, bid_{ti}^D , for every day, t , and in every 10-minute interval in the daytime trading session, I , using the observations, i , when both the nearby and the deferred best bid log changes differ from zero (bid_{ti}^N and $bid_{ti}^D \neq 0$). A similar analysis is performed for the offers, using equation 2.

Equation 2 calculates the correlation between the log change of the nearby best offer, $offer_{ti}^N$, and the log change of the deferred best offer, $offer_{ti}^D$ for every day, t , and in every 10-minute interval in the daytime trading session, I , using the observations, i , when both the nearby and the deferred best offer differ from zero ($offer_{ti}^N$ and $offer_{ti}^D \neq 0$).

$$corr_{tI}^{Offer} = \frac{\sum_{i=1}^n (offer_{ti}^N - \overline{offer_t^N}) (offer_{ti}^D - \overline{offer_t^D})}{\sqrt{\sum_{i=1}^n (offer_{ti}^N - \overline{offer_t^N})^2 \sum_{i=1}^n (offer_{ti}^D - \overline{offer_t^D})^2}} \quad (2)$$

such that $offer_{ti}^N$ and $offer_{ti}^D \neq 0$

The correlations from equations 1 and 2 are calculated for the nearby and one deferred, nearby and two deferred, and nearby and three deferred contracts.

373 5.2. *Speed of Information Transmission and Time-Lagged Correlations in the*
374 *Top of the Book*

375 To provide insights on the speed at which information is transmitted from
376 the nearby to the deferred contracts, we lag the nearby series of log changes
377 in the bid (offer) and calculate the correlation with the deferred bids (offers).
378 This allows us to determine the length of time it takes for information to
379 be fully transmitted to the deferred contracts. The assumption is that the
380 length of time it takes for the revisions to the top of the nearby limit order
381 book to become uncorrelated with revisions to the top of the deferred limit
382 order books is the length of time it takes for information to be transmitted
383 between the two markets.

$$corr_{tI}^{LagBid} = \frac{\sum_{i=2}^n \left(bid_{t(i-1)}^N - \overline{bid_t^N} \right) \left(bid_{ti}^D - \overline{bid_t^D} \right)}{\sqrt{\sum_{i=2}^n \left(bid_{t(i-1)}^N - \overline{bid_t^N} \right)^2 \sum_{i=2}^n \left(bid_{ti}^D - \overline{bid_t^D} \right)^2}} \quad (3)$$

such that $bid_{t(i-1)}^N$ and $bid_{ti}^D \neq 0$

384 Equation 3 calculates the correlation between the lagged log change of
385 the nearby best bid, $bid_{t(i-1)}^N$, and the log change of the deferred best bid,
386 bid_{ti}^D for every day, t , and in every 10-minute interval in the daytime trading
387 session, I , using the observations, i , when both the lagged nearby and the
388 deferred best bid differ from zero ($bid_{t(i-1)}^N$ and $bid_{ti}^D \neq 0$).

$$corr_{tI}^{LagOffer} = \frac{\sum_{i=2}^n \left(offer_{t(i-1)}^N - \overline{offer_t^N} \right) \left(offer_{ti}^D - \overline{offer_t^D} \right)}{\sqrt{\sum_{i=2}^n \left(offer_{t(i-1)}^N - \overline{offer_t^N} \right)^2 \sum_{i=2}^n \left(offer_{ti}^D - \overline{offer_t^D} \right)^2}}$$

such that $offer_{t(i-1)}^N$ and $offer_{ti}^D \neq 0$

(4)

389 Similarly, equation 4 calculates the correlation between the lagged log
 390 change of the nearby best offer, $offer_{t(i-1)}^N$, and the log change of the deferred
 391 best offer, $offer_{ti}^D$ for every day, t , and in every 10-minute interval in the
 392 daytime trading session, I , using the observations, i , when both the lagged
 393 nearby and the deferred best offer differ from zero ($offer_{t(i-1)}^N$ and $offer_{ti}^D \neq$
 394 0).

395 5.3. Spread Trades, Information Transmission, and Time-Lagged Bid-to- 396 Offer (Offer-to-Bid) Correlations

397 Surely the spread trade is an important component that keeps nearby
 398 and deferred contracts linked in economically meaningful ways. However, a
 399 spread trade is entered as a buy (sell) in the nearby and a sell (buy) in the
 400 deferred contract. Until now, we have presented correlations between bid-
 401 to-bid and offer-to-offer in the nearby and deferred contracts. In equation 5,
 402 we measure the effect of spread traders in transmitting information up the
 403 forward curve, by calculating correlations between lagged log changes in the
 404 nearby bid and log changes in the deferred offer.

$$corr_{tI}^{LagBO} = \frac{\sum_{i=1}^n \left(bid_{t(i-1)}^N - \overline{bid_t^N} \right) \left(offer_{ti}^D - \overline{offer_t^D} \right)}{\sqrt{\sum_{i=1}^n \left(bid_{t(i-1)}^N - \overline{bid_t^N} \right)^2 \sum_{i=1}^n \left(offer_{ti}^D - \overline{offer_t^D} \right)^2}} \quad (5)$$

such that $bid_{t(i-1)}^N$ and $offer_{ti}^D \neq 0$

405 More specifically, equation 5 measures the correlation between the lagged
 406 log change of the nearby best bid, $bid_{t(i-1)}^N$, and the log change of the de-
 407 ferred best offer, $offer_{ti}^D$, for every day, t , and in every 10-minute interval
 408 in the daytime trading session, I , using the observations, i , when both the
 409 lagged nearby and the deferred best offer are not equal to zero, when both
 410 the lagged nearby offer and the deferred best offer are different from zero
 411 ($bid_{t(i-1)}^N$ and $offer_{ti}^D \neq 0$).

$$corr_{tI}^{LagOB} = \frac{\sum_{i=1}^n \left(offer_{t(i-1)}^N - \overline{offer_t^N} \right) \left(bid_{ti}^D - \overline{bid_t^D} \right)}{\sqrt{\sum_{i=1}^n \left(offer_{t(i-1)}^N - \overline{offer_t^N} \right)^2 \sum_{i=1}^n \left(bid_{ti}^D - \overline{bid_t^D} \right)^2}} \quad (6)$$

such that $offer_{t(i-1)}^N$ and $bid_{ti}^D \neq 0$

412 Similarly for equation 6 we calculate the same correlations as in equation
 413 5 except that we use the lagged nearby offer and the deferred bid.

414 5.4. USDA Announcement Days

415 On USDA report announcement days there is often a significant amount of
 416 information that market participants receive at the same time, causing large
 417 price fluctuations and larger than usual trading volumes. Therefore, in our
 418 analysis we separate out days on which major USDA reports are released and

419 calculate the same correlations described above. This allows us to examine
420 whether there is a detectable difference in information-based trading and the
421 speed of information transmission on USDA report release days compared
422 to a typical trading day. During our sample period, the USDA reports were
423 released at 8:30 am CST, before the daytime trading session began. We
424 separate days on which the following reports were released: WASDE, Crop
425 Production, Prospective Planting, Planted Acres, and Grain Stocks.

426 **6. Results**

427 Table 2 contains the structure of the results that are presented as figures 2,
428 3, and 4. Figure 2 sheds light on information-based trading and presents the
429 strength of the link between the nearby and deferred contracts by calculating
430 the contemporaneous correlation between log changes of nearby bids (offers)
431 and log changes of deferred bids (offers). Figure 3 investigates the speed of
432 information transmission by presenting the strength of the correlation of log
433 changes of nearby bids (offers) and log changes of first deferred bids (offers)
434 at time lags of 0, 1, and 10 seconds. Figure 4 shows spread trades information
435 transmission through the correlation of log changes of nearby bids (offers)
436 and log changes of first deferred offers (bids) at time lags of 0, 1, and 10
437 seconds. Each figure is organized in a similar way. The top two panes show
438 correlations with the nearby bid and offer, respectively, while the bottom
439 panels show the same information on USDA report days. The dots represent
440 the mean of the distribution of calculated correlations and the bars represent
441 one standard deviation of the distribution of calculated correlations.

442 *6.1. Information-Based Trading Activity and Contemporaneous Correlations*
443 *in the Top of the Book*

444 In figure 2 contemporaneous correlation between the nearby and one, two,
445 and three deferred maturity contracts are displayed. Calculations are made
446 based on time-stamps where both the nearby and deferred maturity experi-
447 ence non-zero revisions to the best bid (top panel) or offer (second panel).
448 The contemporaneous correlations between each nearby and deferred con-
449 tract pairs are very close to one for both best bids (top panel) and best offers
450 (second panel). The exception being that there is a slight dip in correlations
451 at the first and last ten minutes of the trading day.

452 This implies that in the event both contracts experience revisions to their
453 respective limit order books, they are revised in lockstep. While some of this
454 correlation is artificially induced due to the tick structure of price changes
455 in this market (prices move in a minimum of 0.25 cent increments.), the cor-
456 relations are too strong to attribute it all to that. Additionally, since our
457 data is only time-stamped to the second, we may miss nuance that would be
458 captured with data time stamped to the millisecond. Regardless, the result is
459 surprisingly strong and indicates that information is largely transmitted up
460 the forward curve in less than one second. It is interesting that the distribu-
461 tion of correlations between the nearby and 1, 2, and 3 deferred contract bids
462 are at such similar levels, hovering very close to one. Transmission of infor-
463 mation to the third deferred contract seems to be as strong as transmission
464 to the first deferred contract.

465 The bottom two panels of figure 2 are exactly analogous to the top two
466 except that they focus on USDA report days. We see a remarkably similar

467 depiction compared in that the correlations hover near one throughout the
468 trading day. If there had been a difference in the pattern of correlations
469 on USDA report days, one would expect the first ten minutes of trading to
470 display the largest effect. There is visibly more variation in the means of
471 these distributions, which could also be a reflection of the smaller sample of
472 report days versus non-report days.

473 We suspect two primary reasons that the full sample and USDA report
474 day results are so similar: 1) Since we removed days where the report release
475 corresponded to limit price moves, we systematically removed report days
476 where the most important information was conferred on the market. As a
477 result, the remaining days corresponding to USDA reports were more easily
478 translated to market impacts by traders, and thus created results in figure
479 2 that look similar to a normal trading day. 2) Since USDA reports were
480 released prior to the market open during this time period, the information
481 may have already been fully incorporated by market participants by the
482 time the market opened, resulting in no discernible difference in the pattern
483 of correlations in the first (and subsequent) time bins.

484 *6.2. Speed of Information Transmission and Time-Lagged Correlations in the*
485 *Top of the Book*

486 Figure 3 contains the correlations between log changes of the nearby and
487 log changes of one deferred contracts at 0, 1, and 10 second time lags, when
488 both experience non-zero changes. The graph shows the contemporaneous
489 correlation from figure 2 as a reference. Here we expected to see a clear pat-
490 tern of decreased correlation as we increased the length of the time lag in the
491 nearby - reflecting that information is transmitted from nearby to deferred

492 contracts over a number of seconds. However, we see that the correlation
493 drops to zero with a lag of one second, which in this data set is the shortest
494 time lag possible.

495 There are three possible explanations for this. First, it is possible that
496 there is in fact a clear and decreasing correlation between lags of the nearby
497 and the deferreds, but it can only be observed on mili- or micro-second
498 time stamps. Then, when aggregating to the nearest second, we observe
499 contemporaneous correlation close to one, but zero correlation even at the
500 shortest possible time lag (one second).

501 Second, we explicitly assumed that price discovery happens in the nearby
502 contract when we lagged the nearby contract instead of the deferred contract.
503 If price discovery happens in the deferred contract, and takes time to fully
504 to be incorporated into the nearby contract, then we would observe non-
505 zero correlation between nearby quote revisions and lagged *deferred* quote
506 revisions. When we did this, we observed a very similar result as is presented
507 in figure 3 - zero correlation at 1 and 10 second time lags of the deferred
508 contract; this means there is no evidence to support that price discovery
509 happens in the deferred contracts.⁵ Information seems to be fully transmitted
510 within one second to the first deferred contract.

511 Third, zero correlations between the deferred and time lagged nearby
512 would also occur if linkages between the nearby and deferred contracts were
513 immediately enforced by spread traders. This is examined in figure 4.

⁵This figure is not presented in the interest of brevity.

514 6.3. Spread Trades, Information Transmission, and Time-Lagged Bid-to- 515 Offer (Offer-to-Bid) Correlations

516 Figure 4 displays the means and error bars of the correlations between log
517 changes of the lagged nearby bid (offer) revisions and log changes of the first
518 deferred offer (bid) revisions. Here, as in figure 3 we see contemporaneous
519 correlations near one. We observe that while the correlations when the nearby
520 is lagged by both one second and ten seconds are near zero, the mean of the
521 one second lagged correlations are clearly higher than the ten second lags and
522 larger than zero. Despite this minor difference, it is not compelling evidence
523 that we have observed incomplete information transmission at the one second
524 horizon. Though positive, it is still quite close to zero.

525 This result may be surprising because trades in the calendar spread (buy-
526 ing the nearby and selling the deferred, or vice versa) should induce a negative
527 nearby bid-to-deferred offer correlation. Since our results appear very similar
528 to the results in figures 2 and 3, we conclude that the information effect in
529 price levels swamps any negative correlation that would have been induced
530 by the spread trade.

531 7. Conclusions

532 Recent developments in commodity markets make it important to assess
533 price adjustment patterns with high frequency data. We focused this paper
534 on the corn market because it has experienced some of the most pronounced
535 changes in recent years. We gleaned insights from the sequential trading mar-
536 ket microstructure literature to generate metrics of informed versus liquidity
537 trading in commodity futures markets. Sequential trading models allow liq-

538 uidity providers to learn about the existence of information arrivals and their
539 directional implications for security prices. From these models we infer that
540 market makers detect no new market information if we observe no changes
541 to the best bid or best offer in the limit order book. This is because in se-
542 quential trading models, the market maker learns about the probability of
543 an information event from trader order flows and revises his breakeven bids
544 and offers accordingly.

545 We use simple correlations between non-zero log changes to the best bid
546 (offer) in the limit order book as our metric of information-based activity in
547 the market. Our results for CBOT corn indicate that the mean contempo-
548 raneous correlation between non-zero changes to the nearby and all deferred
549 contracts was very close to 1 throughout the trading day. When information
550 arrives to the market, liquidity providers in contracts of all maturities revise
551 their bids and offers in lockstep (or in less than one second) to reflect the
552 new information.

553 To measure the speed of information transfer from nearby to deferred
554 maturities, we lagged the nearby by one and ten second respectively and
555 computed correlations in revisions to the best bid (offer) with deferred con-
556 tracts. We find that even at a one second lag, the shortest time lag possible
557 with this data set, the correlation between revisions to the best bid and best
558 offer dropped to zero.

559 These results provide compelling evidence that traders are able to in-
560 corporate information into the electronic corn futures market very quickly.
561 Arbitrage opportunities that arise from out-dated prices in the deferred con-
562 tracts quickly evaporate with electronic and algorithmic traders (Lehecka,

563 Wang, and Garcia 2014). Informatively, we find little difference between
564 USDA announcement and regular days except for a wider variance, which
565 might be attributed to the larger shocks in information.

566 It also appears that the arrival of new information overwhelms spreading
567 activity. Calendar spread trades should lead to a negative correlation between
568 the nearby and deferred. However, we find that the nearby and deferred
569 contracts have a correlation near 1 concurrent with an information event
570 and a correlation near zero in the absence of such an event. In part, this may
571 be influenced by spread traders who take market positions because of price
572 differentials in contracts rather than the arrival of new information.

573 Finally, we have shown that price discovery across electronically traded
574 commodities can occur quickly even when the known liquidity differences
575 in specific contracts exist (X. Wang, Garcia, and Irwin 2014); if differences
576 occur, they likely occurs at the millisecond level.

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Table 1: First ten entries in our data set.

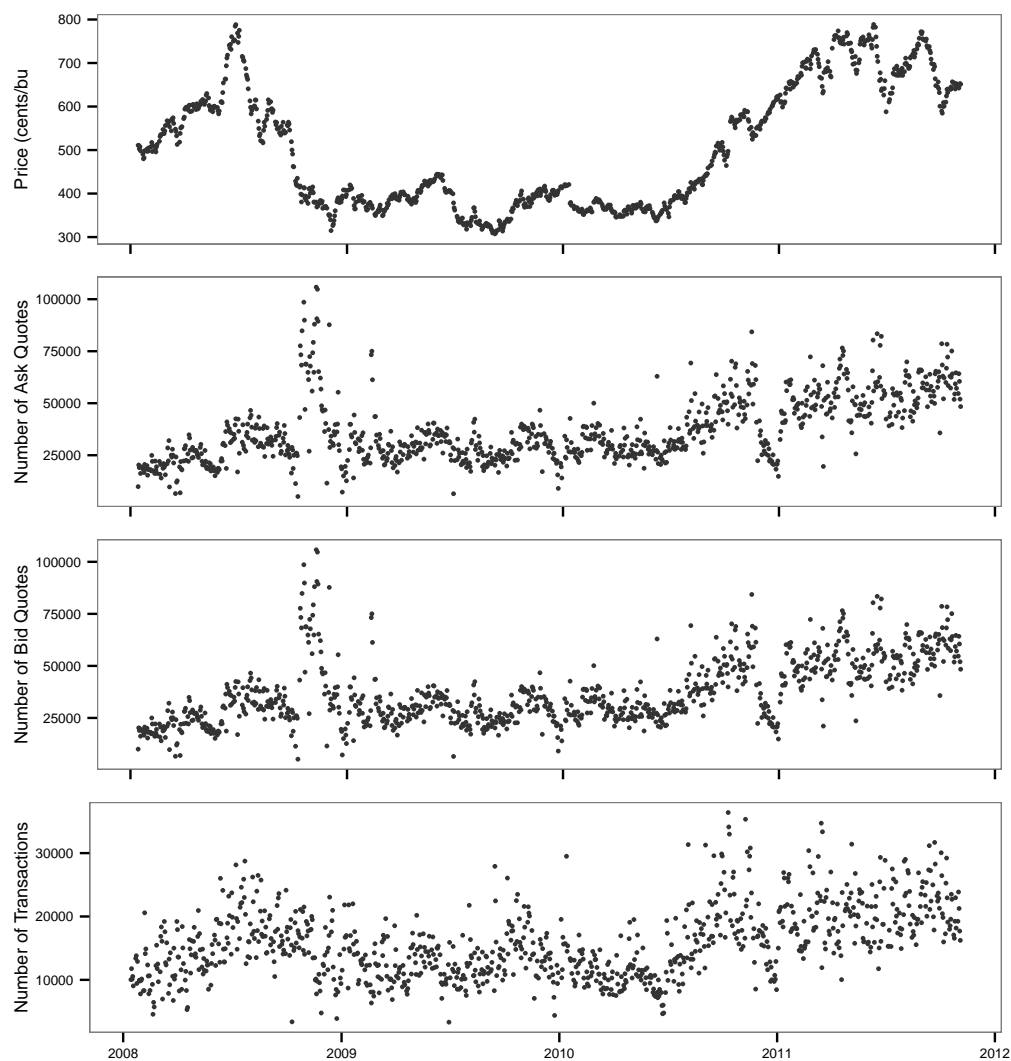
	ID	SYMBOL	OFRSIZ	OFR	BIDSIZ	BID
2010-01-04 09:30:00	98790	1003	1475	423.75	1188	423.75
2010-01-04 09:30:00	98800	1003	1483	423.75	1188	423.75
2010-01-04 09:30:00	98810	1003	1483	423.75	1197	423.75
2010-01-04 09:30:00	98820	1003	1486	423.75	1197	423.75
2010-01-04 09:30:00	98830	1003	1486	423.75	1231	423.75
2010-01-04 09:30:00	98840	1003	1494	423.75	1231	423.75
2010-01-04 09:30:00	98850	1003	1496	423.75	1231	423.75
2010-01-04 09:30:00	98860	1003	1510	423.75	1231	423.75
2010-01-04 09:30:00	98870	1003	1510	423.75	1233	423.75
2010-01-04 09:30:00	98880	1003	1520	423.75	1234	423.75

Notes: ID = CME's trade sequence number, Symbol = Contract expiration year (2010) and month (March), OFRSIZ = Number of contracts at the best offered price, OFR = Best price offered (cents per bushel), BIDSIZ = Number of contracts at the best bid price, BID = Best price bid (cents per bushel).

Table 2: Correlations Calculated to Produce Figures 1, 2, and 3

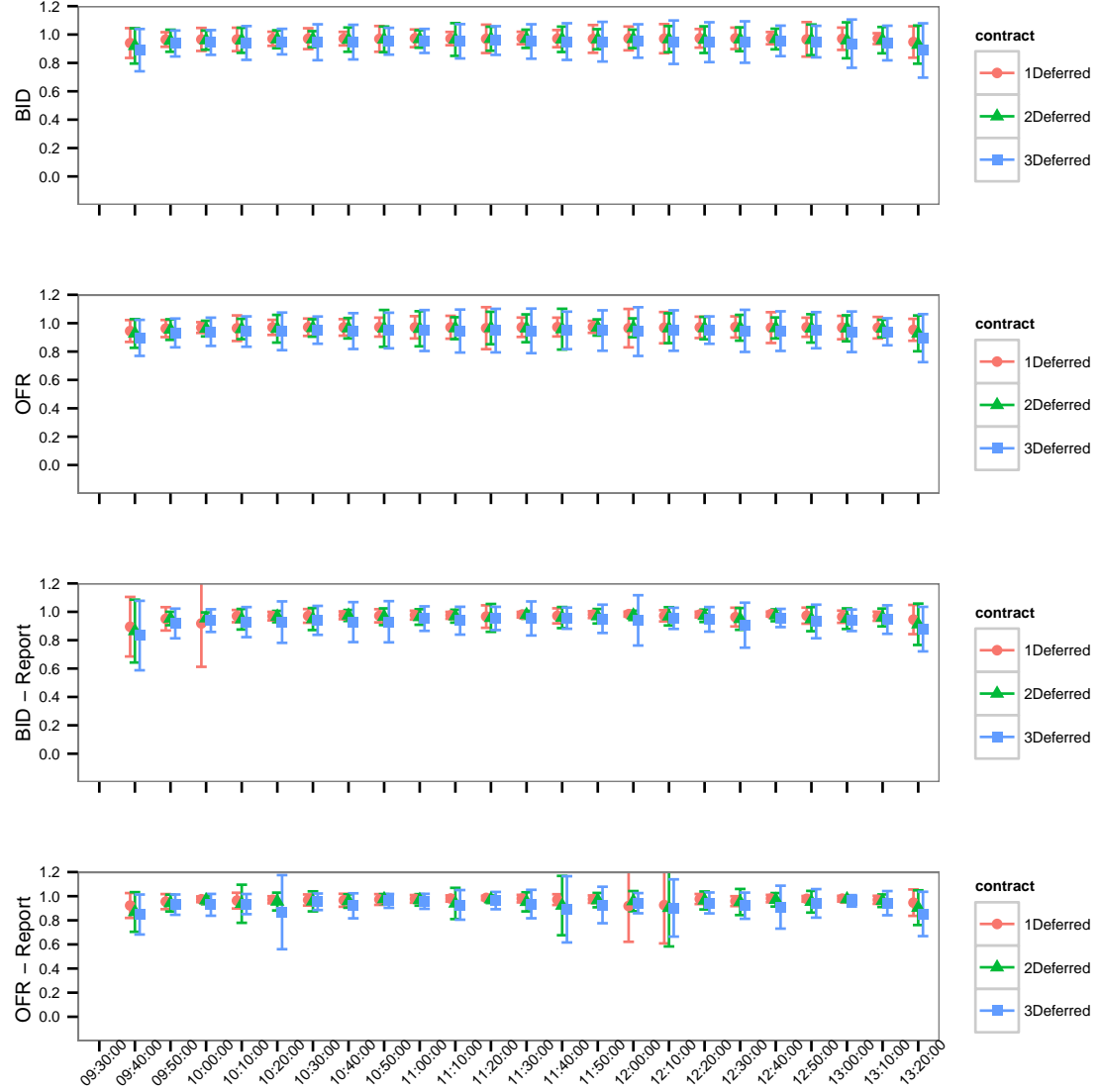
Information-based trading Figure 2 No Time Lag Correlation of Nearby and		Speed of information transmission Figure 3 Time Lag Correlation of Nearby and 1 deferred		Spread trades and information transmission Figure 4 Time Lag Correlation of Nearby and 1 deferred	
Bid to Bid	1 deferred	Bid to Bid	no time lag	Bid to Offer	no time lag
	2 deferred		1 second		1 second
	3 deferred		10 seconds		10 seconds
Offer to Offer	1 deferred	Offer to Offer	no time lag	Offer to Bid	no time lag
	2 deferred		1 second		1 second
	3 deferred		10 seconds		10 seconds
Bid to Bid (Report)	1 deferred	Bid to Bid (Report)	no time lag	Bid to Offer (Report)	no time lag
	2 deferred		1 second		1 second
	3 deferred		10 seconds		10 seconds
Offer to Offer (Report)	1 deferred	Offer to Offer (Report)	no time lag	Offer to Bid (Report)	no time lag
	2 deferred		1 second		1 second
	3 deferred		10 seconds		10 seconds

This table contains a summary of the correlation results that are presented in figures 1, 2, and 3. Correlations are calculated in ten minute intervals and for every day of our sample. The bottom two panels (Report) display the correlations for USDA report release days only.



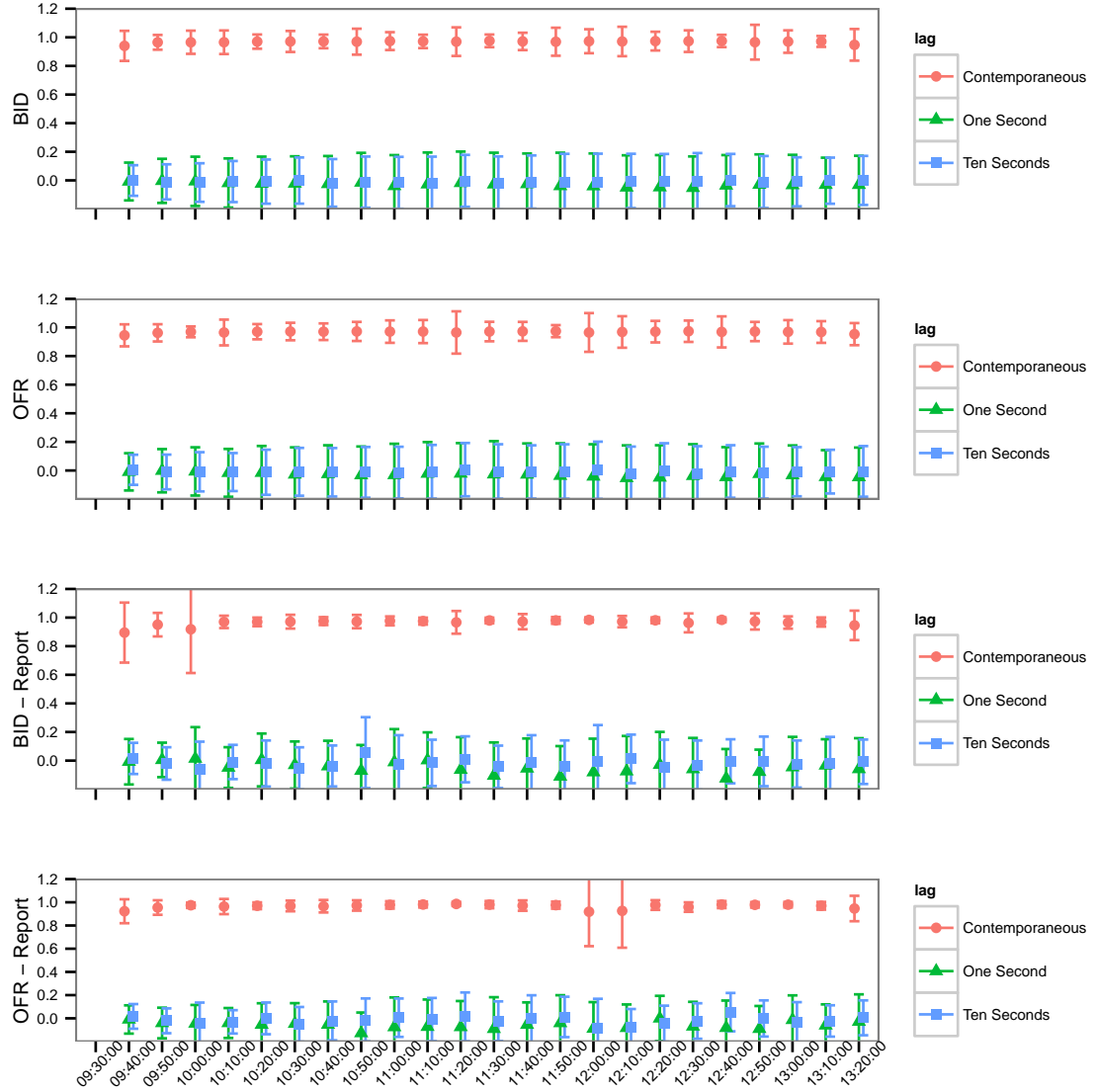
Notes: Figure displays data for the corn futures market from 1/14/2008 to 11/04/2011 for the nearby contract. The September contract is excluded due to the possibility of ‘old crop’ and ‘new crop’ both being delivered on this contract. To form the continuous nearby series contracts are rolled to the next contract on the 20th of the month prior to the delivery month.

Figure 1: Price Levels, Number of Ask Quotes, Number of Bid Quotes, and Number of Transactions



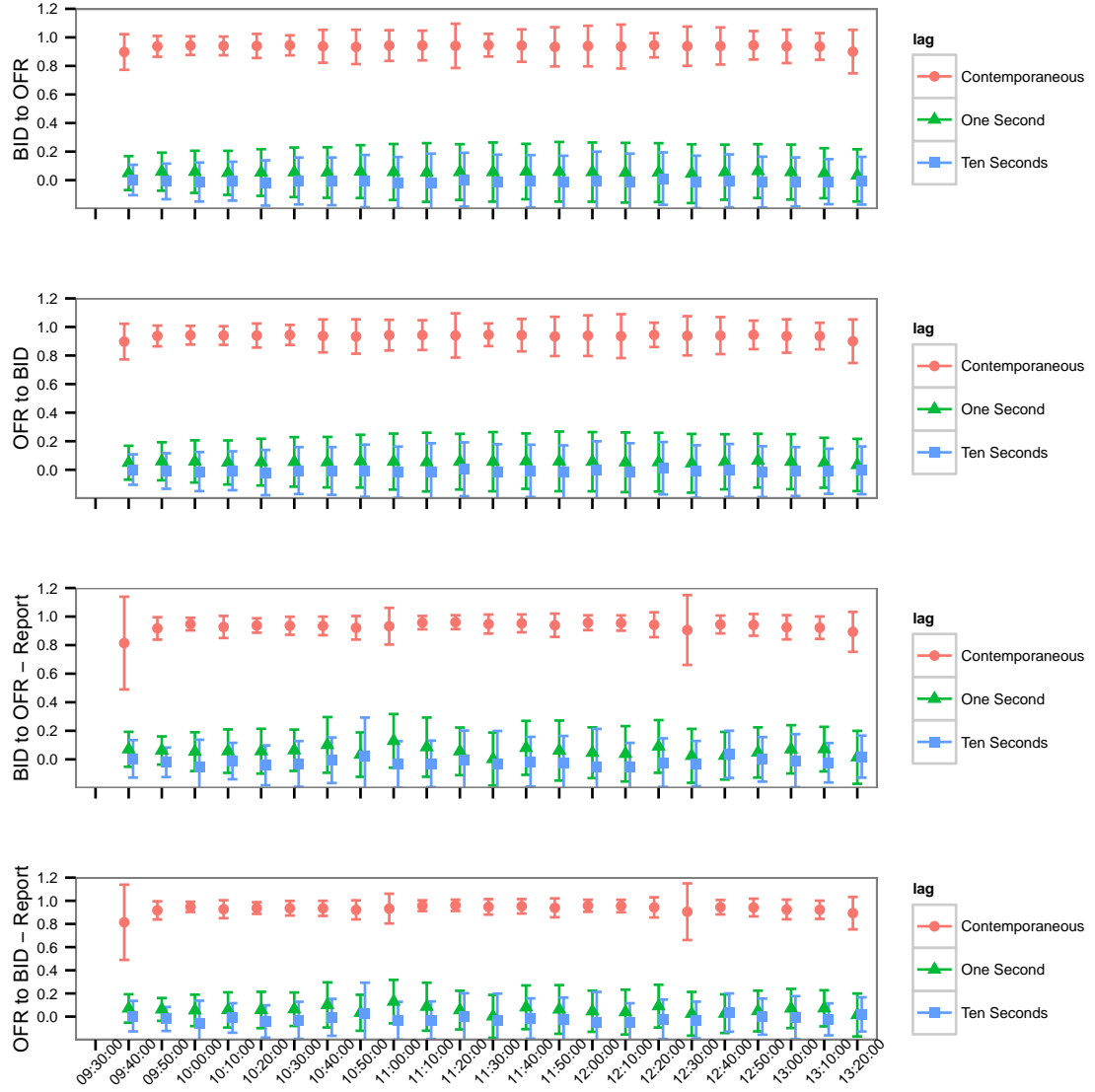
Notes: Mean correlations and one standard deviation error bars over all days are shown in the top two plots; report days only are included in the bottom two plots.

Figure 2: Information-Based Trading Activity and Contemporaneous Correlations in the Top of the Book



Notes: Mean correlations and one standard deviation error bars over all days are shown in the top two plots; report days only are included in the bottom two plots.

Figure 3: Speed of Information Transmission and Time-Lagged Correlations in the Top of the Book



Notes: Mean correlations and one standard deviation error bars over all days are shown in the top two plots; report days only are included in the bottom two plots. Bid-to-Offer shows correlation between revisions to the lagged nearby bid and the first deferred revisions to the offer, and Offer-to-Bid shows correlation between revisions to the lagged nearby offer and the first deferred revisions to the bid.

Figure 4: Spread Trades, Information Transmission, and Time-Lagged Bid-to-Offer (Offer-to-Bid) Correlations