Maximum Order Size and Agricultural Futures Market Quality: *Evidence from a Natural Experiment*

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Abstract

We exploit an exchange-mandated increase of the maximum order size, in the U.S. corn calendar spread market, in order to investigate the connection between exogenous constraints on order placement and execution, volatility, and liquidity. We show that the old maximum of 2,500 contracts was binding, and that demand exists for placing and executing much larger orders. The limit-order book depth (at the best bid and ask) increases dramatically after the exchange quadruples the maximum order size to 10,000 contracts. Intraday realized volatility is not statistically significantly different before and after the rule change. Amid increased market depth and stable volatility, we document that quoted and effective spreads both narrow significantly and that the price impact of large trades is smaller. In sum, market quality is higher after the maximum order size change.

Key words: Maximum order size, Calendar spreads, Liquidity, Volatility.

JEL Classification: G10, G12, G13, G23, Q49.

1. Introduction

Commercial traders and other demanders of immediacy in financial and commodity markets have for years complained that high speed traders provide "phantom liquidity, whereby a large number of orders are placed to create the illusion of liquidity, but are (quickly) cancelled before other traders trying to access those quotes can reach the quoting exchange (Chakrabarty, Huang, and Jain, 2019)." A number of major exchanges have mandated speed bumps as a possible solution. Instead, on July 30, 2018, the CME Group's CBOT quadrupled the maximum order size—from 2,500 to 10,000 contracts—for calendar spread trades in its corn and soybean futures markets (the "Rule Change" hereafter). The Rule Change, which was initially launched as a five-month pilot program, became permanent later on December 31, 2018.

Calendar spread positions account for over a third of the open interest in these two commodity futures markets (Robe and Roberts, 2019), and spread trades make up an even larger portion of the total futures trading volume (Sutton-Vermeulen, 2019). It is therefore critical to identify the Rule Change's impact on agricultural market quality. This is our goal in the present paper. In the process, we also provide novel evidence on the size and composition of the calendar spread market.

The CBOT's Rule Change is said to have come about "at the request of market participants."[1] Consistent with this claim, we document that the previous maximum order size was binding. On the one hand, why some traders would want to place such large spread orders in the first place is not clear: indeed, part of the large literature on market microstructure deals with how the biggest liquidity demanders generally shred large orders so as to minimize their price impact (Van Kerveld and Menkveld, 2019). On the other hand, the four-fold maximum-order-size increase clearly relaxed a massively binding constraint: to wit, we show that (i) transactions with a size larger than

[1] See CME SER-8203R. Available online at: https://www.cmegroup.com/notices/ser/2018/10/SER-8203R.html

2,500 futures account for nearly 20 percent of the total daily trading volume for some calendar spread contracts on certain days after the Rule Change, and (ii) on some days, a single transaction of 10,000 futures makes up more than 10 percent of the daily trading volume for at least one calendar spread maturity. Given this prevalence of large orders and transactions, the total impact of the Rule Change on market quality needs to be examined—both the direct impact on corn and soybean spread trading, and the indirect impact on outright futures trading.

In the present paper, we exploit this unique event to investigate the extent to which trader behavior, return volatility, and market liquidity differ before and after the Rule Change. We use intraday CBOT messaging data to compile detailed information regarding limit order book updates for corn and soybean calendar spread futures. Our sample covers four months from June 1, 2018 to September 30, 2019—two months on each side of the Rule Change's implementation day.[2]

We start with the prevalence of large trades in the sample period. We document that the number and volume share of large transactions (trades of 2,500 contracts or more) both rise after the Rule Change. Next, we turn to the impact of large orders and trades on market quality. Our identification strategy relies on the fact that block trades (which could be an alternative to large trades on the exchange) account for a very small share of the total trading volume in agricultural futures markets.

Precisely, the current draft provides preliminary evidence on the impact of the Rule Change on market quality in the corn calendar spread market based on event studies. The results suggest that market liquidity improves significantly after the Rule Change, as evidenced by (i) increased market depth and (ii) narrower quoted and effective spreads amid (iii) unchanged return volatility. In addition, with increased depth but also greater order sizes, (iv) the price impact of transactions of 2,500 contracts (the previous maximum order size) is significantly lower after the Rule Change.

[2] The present draft focuses on corn. Additional results for soybeans will be available from the authors after July 20.

To the best of our knowledge, our study provides the first investigation of the link between exogenous limits on order size and market quality—not just in commodity futures markets but in any financial market.[3] Additionally, while there exists a large number of studies of market quality in electronically traded agricultural futures markets (e.g. Wang, Garcia, and Irwin, 2014; Haynes, Raman, Robe, and Yadav, 2017; Couleau, Serra, and Garcia, 2019), the present paper is the first to investigate calendar spread markets.

The paper proceeds as follows. Section 2 reviews the extant evidence on the qualitative and quantitative importance of calendar spreading in agricultural futures markets. Section 3 discusses the CBOT's order-execution rules and describes the context within which the Rule Change took place. Section 4 develops our hypotheses. Section 5 presents the data. Section 6 presents summary statistics and describes our hypothesis-test results. Section 7 concludes.

2. On Calendar Spreading in Agricultural Futures Markets

The centrality of calendar spreading in agricultural futures markets has long been recognized.[4] Spreads are particularly important to commercial traders and hedgers of storable commodities, to whom they provide important guidance for storage (e.g., the cost of carry) and for other business decisions. In addition, because calendar spread contracts offer commercial traders a cost- effective and efficient way to roll positions from the front month to the next, contract rolling of grain and oilseed futures positions is often accomplished through calendar spread trades (Sutton-Vermeulen, 2019). In the same vein, Robe and Roberts (2019) show that commercial traders who are not swap

[3] In a contemporaneous white paper, Mallory and Naughton (2020) empirically investigate the CME's order size rule change. Unlike the present paper, they do not investigate the Rule Change's impact on spread market quality and limit their analysis to a single contract month in the corn futures spread market.
[4] In particular, Working (1962) argues that calendar spreading is a key component of commercial activity in grains and oilseeds markets. See Peterson and Choi (2015) and Berdell and Choi (2018) for reviews of the early literature.

dealers (dealers and merchandisers, mostly) rely heavily on calendar spread contracts and make up from a quarter to two fifths of all calendar spread positions in recent years. The present paper's investigation of how commercial traders' spread order execution costs evolve after the 2018 Rule Change, therefore, should be of interest not only to academics but also to regulatory agencies and key futures market participants.

In recent years, calendar spreads account for 34% of all large trader positions in the CME Group's four largest grain and oilseed futures markets (Robe and Roberts, 2019). Measured in terms of its contribution to the total futures trading volume, calendar spreading makes up an even larger percentage of the overall activity. For example, calendar spreads account for between 36% and 64% of the total monthly corn futures trading volume in a 17-month period (January 2018 to May 2019) that straddles the Rule Change—see Sutton-Vermeulen (2019).[5]

Still, even though calendar spreads are widely used in the grain and oilseed futures markets, and even though they are critical to the operations of commercial traders, they have mostly been ignored in empirical studies due to limited data availability. Indeed, Robe and Roberts (2019) is the first paper in a decade to provide systematic evidence, based on regulatory data, regarding overnight positioning in any of those markets.

One of the objectives of the present paper is to close this knowledge gap. We focus on volume and intraday market quality measures rather than on the size and composition of the overnight open interest. As a preamble to our analysis, we present, for the first time, basic but novel market summary statistics regarding the trading volume, quote-update frequency, bid-ask and effective spreads, and depth in the two largest agricultural calendar spread futures markets—which helps

[5] The figure is especially large during contract expiration months: calendar spread trading volume, on average, accounts for approximately 57% of the daily total corn futures trading volume in those months (*ibid*.).

understand the overall market activity and liquidity as well as trader behavior in these markets. Intuitively, one would expect the spread markets to differ markedly from their outright counterparts, starting with intraday volatility—which should be much lower than in the outright market, given that a commodity's cost-of-carry is generally much less volatile than its price is.

3. The 2018 CME Rule Change: Maximum Order Size and Order Matching Algorithm

On July 30, 2018, the CBOT implemented a pilot program (the "Rule Change") quadrupling the maximum order quantity and changing the parameters of the order allocation algorithm in its corn and soybean futures calendar-spread markets.

The Rule Change raises the maximum order quantity from an old maximum of 2,500 contracts to a new maximum of 10,000 contracts for trading calendar spreads on corn and soybean futures. In addition to increasing the maximum order size, the Rule Change also modified the order-matching process in the corn and soybean calendar spread markets. Specifically, it raised the TOP order allocation maximum size from 100 to 1,000 contracts.[6]

On December 31, 2018, the CBOT made this pilot program permanent. Wheat-futures calendar spreads were not subject to the change, however, and both the maximum order size and the matching algorithm remains unchanged for calendar spread trades in wheat futures.

[6] Throughout our sample period, the Split FIFO/Pro-Rata algorithm ("K algorithm") is used in all of CBOT agricultural futures and spread futures markets. The K algorithm first gives priority to the TOP order which is the first incoming limit order that betters the market (tightens the bid-ask spread). Then, the aggressor orders are first allocated to the TOP order. After the TOP order's quantity is exhausted, all tradable quantities in the resting of the order book are allocated on a "40 percent FIFO and 60 percent Pro-Rata" basis. The FIFO algorithm fills orders on a time priority so that the first order at a price level is the first order matched. Instead, the Pro-Rata algorithm fills orders on a percentage basis. An order's pro-rata percentage is computed dividing the order quantity by the total quantity at a certain price. The allocated trade quantity is calculated multiplying an incoming aggressor order's quantity by each resting order's pro-rated percentage. In addition, an order that is not allocated during the Pro-Rata stage is then filled through a pro-rata leveling process during which orders with the largest remaining quantity have priority to be filled.

4. Hypothesis Development and Empirical Design

Under the CBOT's Pro-Rata and Pro-Rata leveling order-matching mechanisms, traders have an incentive to submit limit orders with large quantities in order to get a large allocation of passive fills.[7] Our objective is to investigate the effect of CME's maximum order size rule change on actual order sizes as well as on key measures of intraday market quality. Specifically, we test the following hypotheses:

Hypothesis 1: The old rule limiting order sizes to a maximum of 2,500 contracts was binding. That is, there existed a demand for placing market orders with size greater than 2,500 futures contracts.

The intuition behind Hypothesis 1 is pretty straightforward: there would be no reason for the Rule Change if the old constraints were not binding. Testing this hypothesis requires showing that, *post*-Rule Change, (i) there are a non-trivial number of orders and trades for more than 2,500 contracts and (ii) there are orders and trades of sizes equal to the new maximum.

Hypothesis 2: The Rule Change is not followed by a worsening of traditional measures of market quality including depth, bid-ask spreads, effective spreads, price impact of large trade, or price volatility.

As noted in the Introduction, the CME Group adopted the Rule Change on a trial basis in order to help commercial users (*i.e.*, liquidity demanders), and it made the Change permanent five

[7] Insofar as the outright and spread futures books both use the K-algorithm, it is unlikely that the algorithm itself explains why the order size and market depth would be much larger for in the calendar spread book compared to the outright futures book. A good question, therefore, is whether the huge depth and large orders in the calendar spread market is (i) because spread trading is more often used by commercial hedgers who hold large positions, (ii) because spreads are generally much less volatile than outright prices, or (iii) some other reason. Answering this question is beyond the scope of the present paper.

months later. Intuitively, it is unlikely that the exchange would have persisted if market liquidity had worsened or if volatility had increased significantly in the aftermath of the Rule Change. Hypothesis 2 follows from this observation. We test Hypothesis 2 by providing statistical answers to the following questions:

Hypothesis 2A—Depth: Prior to the Rule Change, liquidity providers could pull back their quotes quickly upon the arrival of a 2,500-contract order. Now, they stand the risk that their quotes might be executed:

i. Did depth at the inside quote used to drop rapidly right after the execution of a 2,500 order? Has the depth reaction to the arrival of a 2,500-contracts order changed?
ii. Do 10,000-contract market orders (in the "post" period) bring about the same type of depth reaction that we used to observe in the case of 2,500-contract orders

Hypothesis 2B—Spreads: What has happened to average spreads? If HFTs used to provide what seemed to be cheap (with small bid-ask spreads) but was in fact "phantom" liquidity (posting orders and then rushing to leave the market following a large trade), then they used to be exposed to 2,500 contracts at the most. Following the rule change, however, posting maximum-size orders could leave them on one side of a 10,000-size trade. Hence, one might expect that spreads are wider in the *post* period than in the *pre* period—whether because HFTs themselves post higher spreads to compensate for that risk, or because HFTs competitive position is weaker and other liquidity providers are now able to raise the price of liquidity.

Hypothesis 2C—Price Impact: A large order may contain information. If, the maximum order size constraint was binding prior to the Rule Change, then liquidity providers would have expected that a 2500-size order was likely the harbinger of more 2500-size orders right after the first order would hit. The same is not true now that the old size constraint is not binding any more. Assuming that the overall market depth (Hypothesis 2A) and average order size (Hypothesis 1) are larger after the Rule Change, one should expect that the price impacts of transactions with a size of 2,500 should decrease and that the price impacts should be more pronounced for transactions of even greater size.

5. Data and Summary Statistics

Our data come from the CME Group's market-depth dataset for electronically-traded calendar spreads of corn futures from June 1, 2018 to September 28, 2018. These data are time-stamped to the millisecond: they provide the detailed market message update information necessary to build the CBOT's limit order book (LOB) and information regarding the sequence of all trades in that market. This dataset provides event-based LOB updates that include (1) create or insert a price, (2) change the quantity for a price at a specific price level, (3) delete or remove a price. For each transaction, the data include the price, size, direction of trade, sequence, and the time when the transaction occurs.

The CME Group commenced its pilot Rule Change program on July 30, 2018. To analyze the quote and trade activity as well as the potential market quality change in response to the rule change, we choose our sample period as two months before and after the commencement of the pilot program.

We focus on the five most traded calendar spread contracts because, in our sample period, (i) all large transactions with sizes larger or equal to 2,500 futures are included in those five contracts and (ii) the volume share of the five most traded ranges from 80% to 88% of the total trading volume for all the actively traded calendar spread contract. To avoid nearby-futures expiration issues, we divide the whole sample period into three sub-periods: June 2018, prior to the delivery period of the July 2018 futures; July to August 2018, prior to the delivery period for the September 2018 futures; and September 2018.

5.1 Trading volume

Table 1 presents the total trading volumes for the five most-traded corn calendar spread contracts; the shares of the trading volume of the five most traded contracts; and the shares of the total trading volume of all active calendar spread contracts[8] during our sample period. The beginning of each sub-period is the first trading day of a contract month. As Table 1 shows, the top-five most traded corn calendar spread contracts account for more than 80% of the total trading volume in all active calendar spread contracts. In each sub-period, the most traded of those five contracts dominates the volume share, making up from about 42 percent to about 60 percent of the total trading volume of the top-five most traded contracts. Not surprisingly, most calendar spread contracts included in our analysis involve the December (Z18) contract which is actively used for market participants for hedging purpose as it reflects the crop harvest.

Table 2 provides summary statistics for the daily trading volume for the five most traded corn calendar spread contracts. Consistent with the term structure presented in Table 1, the daily average trading volume is higher in nearer-dated calendar spread contracts. In addition, we note that the trading volume is lower in September, especially for the most traded contracts, which could reflect seasonal patterns and the transition between the old and new crops.

5.2 Quote Updates

Table 3 reports summary statistics for the daily number of quote updates in the limit order book (up to 10^{th} depth) for each corn calendar spread contract. Quote updates include (1) create or

[8] There are 48, 62, and 54 active calendar spread contracts in June, July-August, and September, respectively.

insert a price at a price level, (2) change the price at a price level, (3) delete a price at a specific price level due to order execution or cancelation.

Overall, Table 3 reveals a rather active corn calendar spread market. The most traded calendar spread contract, on average, has a daily number of quote updates ranging from 184,650 to 213,822 across sub-periods. These figures are equivalent to 637 to 737 updates per minute. For comparison, Hu, Serra and Garcia (2020) document that the average number of outright quote updates at the best bid and best ask (in the limit order book for the corn outright futures with the highest number of quote updates) is 514 between December 2015 and May 2017 . The number of quote updates is often used as a proxy for algorithmic trading activity (Conrad, Wahal, and Xiang, 2015). Insofar as we know that algorithmic trading is prevalent in the corn outright figures market (Haynes and Roberts, 2019; Haynes *et al*. 2017), the frequent quote updates in the corn calendar spread market indicate the presence of algorithmic activity in this market.

5.3 Liquidity and Order Execution Costs

We consider three measures of market liquidity: the limit order book depth, the bid-ask spread, and the effective spread. We calculate the average depth at the best bid and best ask separately for each trading day. For each trading day, we build the LOB for each contract that contains the best bid(ask) value for every message update, and we take the average for each trading day as the daily average for the five most traded contract separately. Table 4 and 5 present summary statistics for the daily average depth at the best bid and ask, respectively. On average, depth for the best bid for the most traded corn calendar spread contract ranges from 110,938 to 146,799 contracts, and depth for the best ask for the most traded corn calendar spread contract ranges from 64,152 to 109,822 contracts.

For comparison, He, Serra, and Garcia (2018) show that the average depth at the best bid or ask is two orders of magnitude smaller—well below 500 contracts during large price movements in the most traded corn outright futures contracts during the period from January 2014 to May 2017. However, considering orders with large sizes are more frequently used in the corn calendar spread market rather than in the outright futures market, large depth at the top of the book does not necessarily mean the liquidity level is high as large orders can consume the depth quickly and order cancelations can widen quoted spreads as well.

To analyze order execution costs in the corn calendar spread market, we calculate the average bid-ask spread and the volume-weighted average effective spread for each trading day. For the *i*th trade in a calendar spread contract, the effective spread, $espread_i$, is defined as

$$espread_i = \frac{I_i(p_i - m_i)}{m_i}, \quad (1)$$

where I_i equals +1 for buyer-initiated trades and −1 for seller-initiated trades; p_i is the trade price; and m_i, t is the quote mid-point prevailing at the time of the trade. For each trading day, we calculate a volume-weighted average effective spread across all trades (using weights that are determined by the shares of the total trading volume for trades during daytime trading hours[9] and express it in basis points (bps).

Table 6 and 7 present summary statistics for daily average bid-ask spreads and daily volume-weighted average effective spreads for the five most traded corn calendar spread contracts in each subperiod, respectively. Table 6 reveals that actively traded corn calendar spread contracts mostly offer order execution at minimal cost, particularly for the top two most traded contracts in each subperiod where bid-ask spreads rarely exceed one tick (0.25 cents/bushel). Table 7 shows that the

[9] Daytime trading for corn futures market is from 8:30 AM to 13:20 PM Central Time in our sample period.

most traded corn calendar spread contracts in each sub-period on average have a mean daily volume-weighted average effective spread under 0.1 bps, except in September 2018. Although Table 6 shows that the quoted bid-ask spreads are not very different across sub-periods, Table 7 shows that the effective spreads, in general, are larger in September compared to June and July-August. As in the case of market depth, this pattern likely reflects the physical-market reality that September is the transition month between old and new crop year with less trading activity.

5.4 Realized Volatility

We calculate realized volatility (RV) for each trading day, for each calendar spread contract. The realized volatility measure is defined as the sum of squares of five-minute non-overlapping price changes[10] and RV_t for trading day *t* is calculated as

$$RV_t = \sum_{j=1}^{58} y_j^2, \tag{2}$$

where y_j^2 is the squared price change over the j^{th} interval and j=1,...,58 as there are 58 five-minute intervals of total 290 minutes during regular trading hours (8:30 a.m.– 13:20 p.m.).

Table 8 reports summary statistics for daily realized volatility for the five most traded corn calendar spread contracts in each sub-period. Higher realized volatility is found in more actively traded calendar spread contracts. In additional, realized volatility, in general, tends to be lower in September—a notable fact, given that depths are lower and spreads are wider in that month.

[10] We do not use log returns as prices (i.e., the spreads, whose value is given by the slope of the term structure of futures prices) are negative in contango.

6. Event Study Results

In this section, we provide preliminary evidence regarding the hypotheses developed in Section 4 by conducting event studies. To avoid seasonal effects and focus purely on the impact of the Rule Change, we tighten our focus on the month (20 trading days) before and after the July 30, 2018 Rule Change. The sample period used for event studies in this section is thus from July 2, 2018 to August 24, 2018.

6.1 Transactions with Large and Maximum Sizes before and after the Rule Change

We begin by documenting that the old maximum order size of 2,500 contacts was binding and that there exists the demand for transactions of larger sizes. To that effect, we focus on large transactions in the most traded contract (ZCU8-ZCZ8), where large transactions are most likely to be observed. This provides a sufficient condition to show the binding nature of the constraint.

Figure 1 plots the number of large transactions for 20 trading days before and 20 trading days after the CME's maximum order size change. Panel A in Figure 1 groups large transactions into two categories: transactions of greater or equal to 2,000 contracts (but less than the old maximum order size of 2,500 contracts) and transactions of exactly 2,500 contracts. Panel B in Figure 1 plots the number of transactions with sizes greater than 2,500 contracts (and thus less than the new maximum order size of 10,000 contracts) and transactions of 10,000 contracts.

Figure 1 shows that, even before the Rule Change, the demand for executing an order of 2,500 contracts existed in 15 out of 20 days in the pre-event window. After the Rule Change, we find multiple transactions with sizes larger than 2,500 contacts in 10 out of 20 days, indicating the old maximum order size was binding. To wit, a trade of the new maximum order size limit of 10,000 contracts was executed just a few days after the Rule Change on August 8, 2018.

Figure 2 presents large transactions' volume shares of the total daily trading volume. For each trading day, we calculate the trading volume of a specific large trade size and divide it by the total daily trading volume. In general, volume share of transactions with sizes less than the previous maximum order size of 2,500 contracts decreases in the post rule change period compared. Large transactions with sizes greater than 2,500 contracts account for nearly 20% of the total volume traded on certain days after the Rule Change. As larger transactions are not only allowed by the new maximum order size change but as we also find that they do take place and account for a fairly large proportion of daily trading volume, the question of market quality after the Rule Change arises. We provide the evidence in the following section.

6.2 The Impact of the Rule Change on Market Quality: A Graphical Analysis

Our interest is in whether the increase of the maximum order size in the corn calendar spread market has a deleterious effect on market quality. To construct series that reflect the overall market liquidity level, we use market-share-weighted liquidity measures. For each trading day, we first obtain the average depth at the best bid and ask, the average bid-ask spread and the volume-weighted average effective spread for each of the five most traded contracts (see Tables 4-7), then we weigh each contract by its total trading volume during the sample period of the event study[11] using the weights presented in Table 1. Using a similar method, we calculate the share-weighted realized volatility for the period before and after the Rule Change. Summary statistics for market quality measures are presented in Table 9.

Figure 3 shows the evolution of the share-weighted depth at the best bid and ask before and after the Rule Change. The depth at the top of the book increases dramatically in the post-Rule

[11] Since most trading days in the event study sample period overlap with the July-August subperiod in table 1, weights used for share-weighted liquidity measures are close to the weights for the July-August subperiod in table 1.

Change period. Since the depth measures are dominated by the ZCU8-ZCZ8 contract and the ZCU8-ZCH9 contract (nearly 70% of the share) when the September (U8) contract is approaching its expiration, the increasing trend in the top of book depth is unlikely to be due to increased market activity.

Figure 4 and 5 display the volume-weighted effective spread and volume-weighted realized volatility, respectively. The effective spread decreases (it ranges from 0.06 to 0.27 basis point before the Rule Change and from 0.06 to 0.20 after the Rule Change) while the realized volatility is stable throughout the whole period.

Figure 6 shows the evolution of the share-weighted bid-ask spread. While the share-weighted bid-ask spread does not change much from the *pre*-Rule Change period, it shows a decreasing trend after the Rule Change—consistent with the increased depth presented in Figure 5. While the above figures show clear trends for depth (increasing) and bid-ask spreads (decreasing), Figure 7 does not display a clearly visible trend for the share-weighted effective spread. Similarly, the share-weighted realized volatility does not seem to change much through the whole event study period, which argues against the possibility that the increased depth and reduced bid-ask spreads are driven by changes in volatility.

5.3 The Impact of the Rule Change on Market Quality: A Statistical Analysis

In order to more formally test whether liquidity in the corn calendar spread market increases significantly after the Rule Change, we conduct bootstrap *t*-tests on parried differences between liquidity and volatility measures in the *pre* and *post* periods and present the results in Table 10. Consistent with the visual observations, the mean of the share-weighted realized volatility does not change significantly after the Rule Change. In contrast, market liquidity is significantly better after Change: the top-of-the-book depth increases significantly, the bid-ask spread is significantly lower, and even the share-weighted effective spread declines (at the 10% level of significance, which is consistent with the hard-to-see visual evidence in Figure 7) .

Overall, these results indicate that (i) our three measures of market liquidity in the corn calendar spread market is significantly better after the Rule Change and (ii) these improvements are more likely to be linked to the Rule Change itself rather to changes in the underlying market volatility (as the latter does not differ significantly in the *pre*- and *post*-periods).

5.4 Price Impacts of Large Trades of 2,500 Contracts

One possible explanation for the improved liquidity shown above is that dramatically increased depth makes it more cost-effective to execute relatively large transactions. In particular, transactions with sizes that are close to the *pre*-Rule Change maximum now should have reduced price impacts as the overall market depth and order sizes have both increased. To verify this intuition, we compute price impacts (*price_impact*) for transactions with a size of 2,500 contracts for the most traded calendar spread contract (ZCU8-ZCZ8) before and after the Rule Change. The price impact for the *i*-th transaction is defined as

$$price\_impact_i = \frac{I_i(m_{i+n} - m_{i,t})}{m_i}, \tag{3}$$

where n is the time lag after the transaction, and we consider different lag values ranging from 2ms (milliseconds) to 30 minutes for n. There are 21 (*resp*. 25) transactions of 2,500 contracts in the 20 trading days before (*resp*. after) the Rule Change, respectively.

Figure 7 presents the average price impact of 2,500-size trades before and after the Rule Change using time lags ranging from 2ms to 30 minutes. As expected, the average price impact of a 2,500-contract transaction is visibly lower in the post-Rule Change period using time lags between 10ms and 50ms.[12]

Figure 6 also shows that the price impact gets stabilized after 75ms in both pre- and post- event periods. However, this does not indicate that the price impact of trades with a size equal to 2,500 contracts is permanent, rather it is because calendar spread price does not change frequently within a day as it is mainly determined by storage costs and interest rate that are typically fixed in commercial settings within a day.

7. Conclusions and Further Work

On July 30, 2018, the CBOT increased the maximum order size from 2,500 to 10,000 contracts in its corn calendar-spread markets. We use this development to show that the previous maximum order size of 2,500 contracts was binding and that there exists a demand for placing and executing orders larger than 2,500 contracts. Next, we show that the limit order book depth at the best bid and ask increases massively following the maximum order size change. Alongside the greater market depth, both quoted and effective spreads are narrower after the Rule Change.

The improved market liquidity is not likely a reflection of underlying market fundamental conditions, given that realized volatility is stable before and after the Rule Change. Rather, we argue that the improvement in market liquidity is more likely because of reduced price impact of large transactions as the overall market depth is dramatically increased after the Rule Change.

The present paper offers several roads for further research.

[12] We do not find these differences are significantly different using 1000-bootstrap *t*-tests. However, this could be a result of the small sample size. In the future, we plan to run robustness checks by including more contracts and by extending the sample period to increase the sample size.

First, our findings suggest that allowing for large orders does not hurt market liquidity in the corn calendar spread market. A natural question is whether those suggestive findings are causal. A related question is whether, even if the Rule Change caused the improvement, the latter can be traced to its maximum-size increase, to its modification the order-matching algorithm, or a combination of both. The problem here is how to tease out the respective impacts of (i) order size increase from (ii) the K-algorithm changes from (iii) market factors. The solution is to exploit concomitant developments in the soybean and wheat futures markets. In the soybean calendar spread market, in the month following the Rule Change, we find a single transaction for more contracts than the old maximum—suggesting that the order size limit was not binding. Hence, any difference between *post*-event market-quality differences for corn *vs*. soybeans may reasonably be attributed to the Rule Change's order-size increase component (i.e., the relaxation of an exogenous constraint on the maximum order size). In turn, because wheat calendar spreads were not subject to either aspect of the Rule Change (*i.e*., neither to the maximum-order-size increase nor to the execution algorithm parameter changes), any difference between wheat and soybeans may in urn be reasonably attributed to the algorithm change (since, in practice, size limits were not binding for soybeans).

Second, even if we establish causality (running from the Rule Change to the improvement in market liquidity after the Rule Change), the question will remain as to the channel. One candidate explanation is that high frequency traders respond to the Rule Change in the corn, but not other, calendar spread market. The finance literature shows that automated trading in general, and high frequency trading in particular, improves liquidity (see, e.g., Hendershott, Jones and Menkveld, 2011; Conrad, Jones and Xiang, 2015). In the next version of this paper, we plan to show whether high frequency trading (proxied by the message-to-trade ratio) changes after the rule change.

Third, our analysis is currently restricted to the calendar spread limit-order book. However, the spread and outright limit-order books are connected through the exchange's implied matching functionality.[13] Thus, even though the 2018 Rule Change is limited to the corn and soybean calendar spread markets, it is possible that it may also indirectly affect the outright futures market through the execution of large calendar spread trades. For this reason, we also plan to investigate whether the Rule Change affects outright market quality. This extension will be the first investigation of the impact of implied-matching functionality on market quality in commodity futures markets. Put differently, future drafts will also shed light on understanding the liquidity provision dynamics between the outright and spread books by providing the empirical evidence of how the Rule Change in the spread book affect liquidity in the outright market.

[13] For CBOT commodity futures contracts, liquidity provision in the spread book can affect and be affected by the outright book as the two order books are conjoined by implied orders. An "implied order" can be either a spread order created based on orders in the outright book ("implied-in") or an outright order created based on orders in the spread market ("implied-out"). Specifically, in the case of implied-in orders, an order in the spread book can be matched "with a combination of orders in the legs of the spread" (individual futures contracts that make up the calendar spread contract) from the outright book (CME, 2020). Similarly, in the case of implied-out orders, an outright order in a leg can be matched with a combination of orders from a calendar spread composed of this leg and orders of the other leg of the spread in the corresponding outright book. The implied orders are created simultaneously in the CME Globex trading platform without causing the risk of being double-filled or partially-filled.

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Table 1. Trading Volume, Weight and Volume Share - Five Most Traded Calendar Contracts

Sample Period	Contract	Total Volume	Weight	Volume Share
June	ZCN8-ZCU8	1,143,444	41.73	36.70
	ZCN8-ZCZ8	824,611	30.09	26.47
	ZCU8-ZCZ8	571,643	20.86	18.35
	ZCZ8-ZCH9	139,085	5.08	4.46
	ZCN8-ZCH9	61,411	2.24	1.97
July and August	ZCU8-ZCZ8	1,775,401	59.36	48.91
	ZCZ8-ZCH9	595,370	19.91	16.40
	ZCU8-ZCH9	327,541	10.95	9.02
	ZCZ8-ZCN9	168,236	5.62	4.63
	ZCZ8-ZCZ9	124,362	4.16	3.43
September	ZCZ8-ZCH9	502,005	52.05	41.63
	ZCH9-ZCK9	149,607	15.51	12.41
	ZCZ8-ZCN9	115,783	12.00	9.60
	ZCZ8-ZCK9	106,972	11.09	8.87
	ZCZ8-ZCZ9	90,185	9.35	7.48

Notes: This table reports total trading volumes, weights and volume shares for the five most traded corn calendar spread contracts in three subperiods: June 2018, July to August 2018, and September 2018. Total volume is the total volume traded in the corresponding subperiod. Weight is computed using the total trading volume of a calendar spread contract divided by the total trading volume of the five most traded calendar spread contracts in the corresponding subperiod. Volume share of a calendar spread contract is its share of the total trading volume for all the active contracts in the corresponding sample period. A corn calendar spread futures contract involves two 5000-bushel corn outright futures contracts. CME contract symbols: H(MAR), K(MAY), N(JUL), U(SEP), Z(DEC); ZC stands for CBOT corn futures; 8 (9) indicates the year of 2018 (2019). Trading hours during the sample period are from 8:30 a.m. to 13:20 p.m. (Central Time).

Table 2. Summary Statistics of Trading Volume - Five Most Traded Calendar Contracts

Sample Period	Contract	Mean	Median	Std.dev.	Min	Max
June	ZCN8-ZCU8	50,412	55,853	24,038	12,622	97,725
	ZCN8-ZCZ8	36,200	36,626	13,036	12,906	69,938
	ZCU8-ZCZ8	23,307	22,099	10,481	6,352	45,995
	ZCZ8-ZCH9	5,656	4,711	2,728	2,428	12,088
	ZCN8-ZCH9	2,659	2,481	974	1,226	5,071
	Contract	Mean	Median	Std.dev.	Min	Max
July and August	ZCU8-ZCZ8	36,170	29,925	21,316	7,446	79,530
	ZCZ8-ZCH9	11,964	11,648	6,176	1,819	30,106
	ZCU8-ZCH9	6,470	6,169	2,810	921	12,635
	ZCZ8-ZCN9	3,264	2,541	2,108	526	9,825
	ZCZ8-ZCZ9	2,402	1,919	1,433	728	7,055
	Contract	Mean	Median	Std.dev.	Min	Max
September	ZCZ8-ZCH9	25,370	25,016	12,105	5,331	58,841
	ZCH9-ZCK9	7,360	4,750	7,035	658	26,545
	ZCZ8-ZCN9	5,540	3,455	4,866	1,665	21,786
	ZCZ8-ZCK9	5,096	4,583	2,989	1,380	14,704
	ZCZ8-ZCZ9	4,321	3,471	2,644	1,500	10,813

Notes: This table reports summary statistics for daily trading volumes for the five most traded corn calendar spread contracts in three subperiods: June 2018, July to August 2018, and September 2018. A corn calendar spread futures contract involves two 5000-bushel corn outright futures contracts. CME contract symbols: H(MAR), K(MAY), N(JUL), U(SEP), Z(DEC); ZC stands for CBOT corn futures; 8 (9) indicates the year of 2018 (2019). Trading hours during the sample period are from 8:30 a.m. to 13:20 p.m. (Central Time).

Table 3. Summary Statistics of Quote Updates - Five Most Traded Calendar Contracts

Sample Period	Contract	Mean	Median	Std.dev.	Min	Max
	ZCN8-ZCU8	213,822	203,012	71,268	67,677	337,450
	ZCN8-ZCZ8	262,770	244,985	71,940	115,782	423,796
June	ZCU8-ZCZ8	232,375	213,579	60,447	143,764	393,303
	ZCZ8-ZCH9	135,375	132,472	38,229	84,966	212,890
	ZCN8-ZCH9	128,329	117,122	39,598	77,958	222,739
	Contract	Mean	Median	Std.dev.	Min	Max
	ZCU8-ZCZ8	203,955	191,064	57,193	56,098	360,628
	ZCZ8-ZCH9	111,858	108,772	30,093	72,993	220,843
July and August	ZCU8-ZCH9	115,447	114,781	29,155	21,449	187,263
	ZCZ8-ZCN9	65,200	57,428	28,301	29,195	190,975
	ZCZ8-ZCZ9	86,126	78,826	33,857	49,649	221,270
	Contract	Mean	Median	Std.dev.	Min	Max
	ZCZ8-ZCH9	184,650	167,795	52,677	121,601	304,372
	ZCH9-ZCK9	119,918	114,817	32,292	67,265	201,430
September	ZCZ8-ZCN9	81,694	80,899	27,691	42,126	149,932
	ZCZ8-ZCK9	108,437	101,936	33,153	63,968	195,189
	ZCZ8-ZCZ9	84,692	75,952	32,850	41,133	162,901

Notes: This table reports summary statistics for the daily number of quote updates for the five most traded corn calendar spread contracts in three subperiods: June 2018, July to August 2018, and September 2018. Quote updates include create/ insert a price at a certain price level, and change/ delete a price at a specific price level. A corn calendar spread futures contract involves two 5000-bushel corn outright futures contracts. CME contract symbols: H(MAR), K(MAY), N(JUL), U(SEP), Z(DEC); ZC stands for CBOT corn futures; 8 (9) indicates the year of 2018 (2019). Trading hours during the sample period are from 8:30 a.m. to 13:20 p.m. (Central Time).

Table 4. Summary Statistics of Daily Average Best Bid Depth - Five Most Traded Calendar Contracts

Sample Period	Contract	Mean	Median	Std.dev.	Min	Max
	ZCN8-ZCU8	131,367	147,875	70,073	882	246,213
	ZCN8-ZCZ8	7,500	7,927	3,666	2,636	14,639
June	ZCU8-ZCZ8	19,361	13,866	13,094	3,788	50,829
	ZCZ8-ZCH9	4,192	4,214	2,146	1,440	8,876
	ZCN8-ZCH9	1,100	1,209	384	496	1,767
	Contract	Mean	Median	Std.dev.	Min	Max
	ZCU8-ZCZ8	146,799	149,921	61,496	990	28,6244
	ZCZ8-ZCH9	28,858	19,742	23,763	4,499	98,744
July and August	ZCU8-ZCH9	6,299	5,255	3,308	59	13,785
	ZCZ8-ZCN9	1,495	1,252	883	447	4,686
	ZCZ8-ZCZ9	125	111	55	28	287
	Contract	Mean	Median	Std.dev.	Min	Max
	ZCZ8-ZCH9	110,938	114,649	61,324	8,874	216,242
	ZCH9-ZCK9	11,360	9,765	6,336	2,325	27,161
September	ZCZ8-ZCN9	2,115	1,321	1,446	803	5,508
	ZCZ8-ZCK9	3,302	2,953	1,277	1,653	5,870
	ZCZ8-ZCZ9	199	169	106	113	565

Notes: The average best bid depth is calculated for each trading day, and this table reports summary statistics for the daily average best bid depth for the five most traded corn calendar spread contracts in three subperiods: June 2018, July to August 2018, and September 2018. A corn calendar spread futures contract involves two 5000-bushel corn outright futures contracts. CME contract symbols: H(MAR), K(MAY), N(JUL), U(SEP), Z(DEC); ZC stands for CBOT corn futures; 8 (9) indicates the year of 2018 (2019). Trading hours during the sample period are from 8:30 a.m. to 13:20 p.m. (Central Time).

Table 5. Summary Statistics of Daily Average Best Ask Depth - Five Most Traded Calendar Contracts

Sample Period	Contract	Mean	Median	Std.dev.	Min	Max
June	ZCN8-ZCU8	109,822	121,079	61,644	1,026	207,362
	ZCN8-ZCZ8	6,556	6,984	2,767	2,570	11,581
	ZCU8-ZCZ8	9,325	6,663	6,125	2,811	31,315
	ZCZ8-ZCH9	2,140	2,017	768	1,113	4,014
	ZCN8-ZCH9	684	649	238	355	1,129
	Contract	Mean	Median	Std.dev.	Min	Max
July and August	ZCU8-ZCZ8	64,152	42,863	61,231	870	237,864
	ZCZ8-ZCH9	15,099	10,572	11,360	2,781	53,989
	ZCU8-ZCH9	3,513	3,278	1,417	73	7,563
	ZCZ8-ZCN9	845	710	471	241	2,239
	ZCZ8-ZCZ9	83	73	38	27	200
	Contract	Mean	Median	Std.dev.	Min	Max
September	ZCZ8-ZCH9	84,118	65,093	51,339	10,974	195,939
	ZCH9-ZCK9	7,843	6,592	4,780	2,973	19,916
	ZCZ8-ZCN9	1,342	1,257	449	745	2,490
	ZCZ8-ZCK9	2,703	2,780	577	1,516	3,684
	ZCZ8-ZCZ9	192	179	80	84	423

Notes: The average best ask depth is calculated for each trading day, and this table reports summary statistics for the daily average best ask depth for the five most traded corn calendar spread contracts in three subperiods: June 2018, July to August 2018, and September 2018. A corn calendar spread futures contract involves two 5000-bushel corn outright futures contracts. CME contract symbols: H(MAR), K(MAY), N(JUL), U(SEP), Z(DEC); ZC stands for CBOT corn futures; 8 (9) indicates the year of 2018 (2019). Trading hours during the sample period are from 8:30 a.m. to 13:20 p.m. (Central Time).

Table 6. Summary Statistics of Daily Average Bid-Ask Spread - Five Most Traded Calendar Contracts

Sample Period	Contract	Mean	Median	Std.dev.	Min	Max
	ZCN8-ZCU8	0.2500	0.2500	0.0000	0.2500	0.2501
	ZCN8-ZCZ8	0.2503	0.2501	0.0005	0.2500	0.2515
June	ZCU8-ZCZ8	0.2505	0.2500	0.0008	0.2500	0.2523
	ZCZ8-ZCH9	0.2514	0.2500	0.0028	0.2500	0.2615
	ZCN8-ZCH9	0.2642	0.2628	0.0115	0.2518	0.3008
	Contract	Mean	Median	Std.dev.	Min	Max
	ZCU8-ZCZ8	0.2503	0.2500	0.0014	0.2500	0.2592
	ZCZ8-ZCH9	0.2506	0.2500	0.0016	0.2500	0.2566
July and August	ZCU8-ZCH9	0.2547	0.2506	0.0135	0.2500	0.3373
	ZCZ8-ZCN9	0.2624	0.2608	0.0118	0.2500	0.3023
	ZCZ8-ZCZ9	0.2872	0.2841	0.0205	0.2542	0.3469
	Contract	Mean	Median	Std.dev.	Min	Max
	ZCZ8-ZCH9	0.2502	0.2500	0.0010	0.2500	0.2542
	ZCH9-ZCK9	0.2501	0.2500	0.0002	0.2500	0.2507
September	ZCZ8-ZCN9	0.2585	0.2541	0.0102	0.2500	0.2859
	ZCZ8-ZCK9	0.2529	0.2521	0.0038	0.2500	0.2663
	ZCZ8-ZCZ9	0.2704	0.2705	0.0103	0.2549	0.2931

Notes: This table reports the summary statistics of bid-ask spread (cents) for the most traded five corn futures spread contracts. The summary statistics are computed using daily average. For example, the minimum daily average bid-ask spread for the contract ZCN8-ZCH9 with the least liquidity in June is 0.2518. Each corn spread futures contract involves two corn futures contracts, and the contract size of corn futures is 5,000 bushels. Our sample period is from June 1, 2018 to September 28, 2018, with trading hours from 8:30 am to 13:20 pm Central Time. CME contract symbol: H(MAR), K(MAY), N(JUL), U(SEP), Z(DEC), ZC stands for CBOT corn futures, and 8 (9) indicates year 2018 (2019).

Table 7. Summary Statistics of Daily Volume-Weighted Average Effective Spread - Five Most Traded Calendar Contracts

Sample Period	Contract	Mean	Median	Std.dev.	Min	Max
June	ZCN8-ZCU8	0.0932	0.0779	0.0648	0.0429	0.3482
	ZCN8-ZCZ8	0.0455	0.0434	0.0183	0.0214	0.0905
	ZCU8-ZCZ8	0.1470	0.1127	0.1056	0.0598	0.5084
	ZCZ8-ZCH9	0.5937	0.4701	0.3712	0.1538	1.6953
	ZCN8-ZCH9	0.1784	0.1526	0.1149	0.0431	0.5444
	Contract	Mean	Median	Std.dev.	Min	Max
July and August	ZCU8-ZCZ8	0.0731	0.0582	0.0533	0.0204	0.3137
	ZCZ8-ZCH9	0.1853	0.1794	0.0806	0.0684	0.4947
	ZCU8-ZCH9	0.2013	0.1881	0.1019	0.0469	0.4652
	ZCZ8-ZCN9	0.4115	0.3503	0.2620	0.1112	1.4831
	ZCZ8-ZCZ9	0.1625	0.1522	0.0969	0.0443	0.5677
	Contract	Mean	Median	Std.dev.	Min	Max
September	ZCZ8-ZCH9	0.1426	0.1178	0.0663	0.0786	0.3257
	ZCH9-ZCK9	0.9375	0.9051	0.5952	0.2221	2.1278
	ZCZ8-ZCN9	0.2748	0.2440	0.1527	0.0622	0.7717
	ZCZ8-ZCK9	0.3050	0.2667	0.2093	0.0570	0.8834
	ZCZ8-ZCZ9	0.1300	0.1100	0.0582	0.0427	0.2499

Notes: This table reports summary statistics for daily volume-weighted average effective spreads for the most traded five corn futures spread contracts. For each trading day, we calculate a volume-weighted average effective spread across all trades using weights that are determined by shares of the total trading volume for trades during trading hours and express it in basis points (bps). A corn calendar spread futures contract involves two 5000-bushel corn outright futures contracts. CME contract symbols: H(MAR), K(MAY), N(JUL), U(SEP), Z(DEC); ZC stands for CBOT corn futures; 8 (9) indicates the year of 2018 (2019). Trading hours during the sample period are from 8:30 a.m. to 13:20 p.m. (Central Time).

Table 8. Summary Statistics of Daily Realized Volatility - Five Most Traded Calendar Contracts

Sample Period	Contract	Mean	Median	Std.dev.	Min	Max
June	ZCN8-ZCU8	0.0179	0.0178	0.0041	0.0120	0.0272
	ZCN8-ZCZ8	0.0031	0.0032	0.0009	0.0018	0.0049
	ZCU8-ZCZ8	0.0078	0.0073	0.0023	0.0038	0.0119
	ZCZ8-ZCH9	0.0072	0.0070	0.0032	0.0026	0.0143
	ZCN8-ZCH9	0.0011	0.0011	0.0005	0.0001	0.0022
	Contract	Mean	Median	Std.dev.	Min	Max
July and August	ZCU8-ZCZ8	0.0052	0.0059	0.0026	0.0004	0.0091
	ZCZ8-ZCH9	0.0069	0.0067	0.0025	0.0014	0.0126
	ZCU8-ZCH9	0.0013	0.0013	0.0005	0.0002	0.0029
	ZCZ8-ZCN9	0.0016	0.0013	0.0010	0.0004	0.0050
	ZCZ8-ZCZ9	0.0033	0.0021	0.0038	0.0009	0.0206
	Contract	Mean	Median	Std.dev.	Min	Max
September	ZCZ8-ZCH9	0.0076	0.0077	0.0024	0.0030	0.0117
	ZCH9-ZCK9	0.0078	0.0071	0.0033	0.0032	0.0157
	ZCZ8-ZCN9	0.0017	0.0015	0.0010	0.0006	0.0050
	ZCZ8-ZCK9	0.0020	0.0019	0.0009	0.0008	0.0040
	ZCZ8-ZCZ9	0.0024	0.0015	0.0036	0.0005	0.0163

Notes: This table reports the summary statistics of the daily average of five-minutes realized volatility for the most traded five corn futures spread contracts. Realized volatility is define as the sum of squares of five-minute non-overlapping price changes during trading hours. A corn calendar spread futures contract involves two 5000-bushel corn outright futures contracts. CME contract symbols: H(MAR), K(MAY), N(JUL), U(SEP), Z(DEC); ZC stands for CBOT corn futures; 8 (9) indicates the year of 2018 (2019). Trading hours during the sample period are from 8:30 a.m. to 13:20 p.m. (Central Time).

Table 9. Summary Statistics for *Pre*- and *Post*- Rule Change Market Quality Measures for Corn Calendar Spread Futures Market (20 days pre and post the rule change)

	Pre Period				*Post* Period			
Variable (unit)	Mean	Std.dev.	Min	Max	Mean	Std.dev.	Min	Max
Best bid depth (number of contract)	90,018	43,395	5,707	176,372	116,645	33,022	54,027	176,372
Best ask depth (number of contract)	18,710	13,896	2,885	57,960	50,664	28,567	10,378	123,549
Bid-ask spread (cents)	0.2537	0.0012	0.2509	0.2565	0.2520	0.0019	0.2505	0.2580
Weighted effective spread (bps)	0.1455	0.0472	0.0586	0.2744	0.1208	0.0390	0.0649	0.2038
Realized volatility	0.0048	0.0022	0.0014	0.0100	0.0050	0.0015	0.0019	0.0077

Notes: This table shows the summary statistics for 20 days of pre and post rule change period market quality metrics. Best bid depth and best ask depth are daily average number of contracts available at the top of the book. Bid-ask spread is the daily average bid-ask spread. Weighted effective spread is the volume weighted effective spread in bps. Realized volatility the calculated as the square sum of all five-min price returns. All metrics are calculated separately for the five most traded contract and weighted by the trading volume.

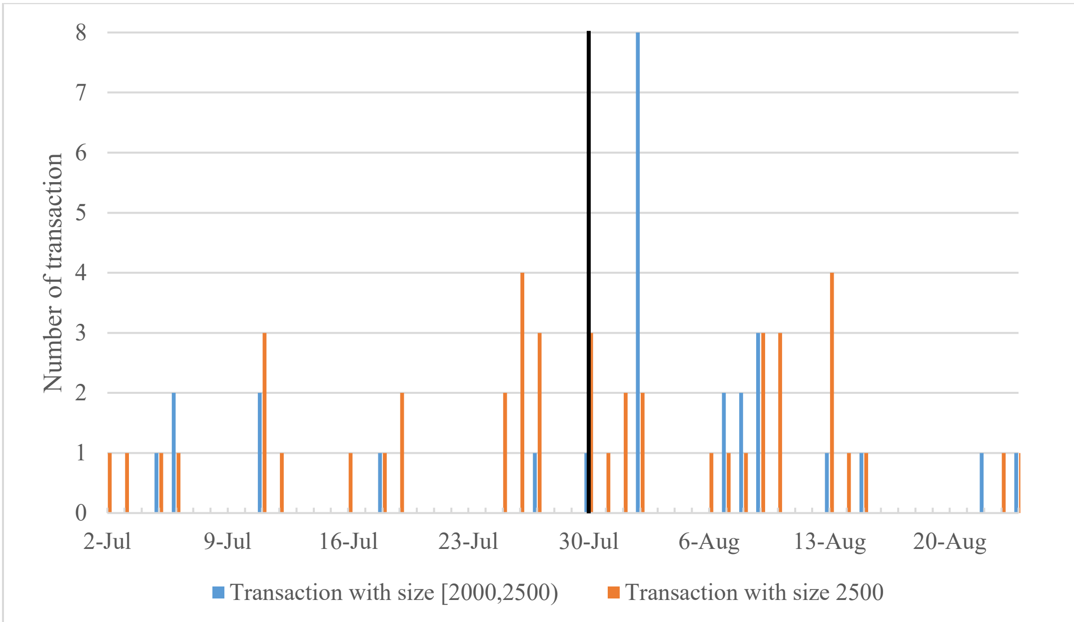
Table 10. T-test for *Pre*- and *Post*- Rule Change Market Quality Measures for Corn Calendar Spread Futures Market (20 days pre and post the rule change)

Variable (unit)	Pre	Post	Difference	P-value (H1: D≠0)
Best bid depth (number of contract)	90,018	116,645	26,627	0.01
Best ask depth (number of contract)	18,710	50,664	31,954	0.00
Bid-ask spread (cents)	0.2537	0.2520	-0.0017	0.00
Weighted effective spread (bps)	0.1455	0.1208	-0.0247	0.08
Realized volatility	0.0048	0.0050	0.0002	0.74

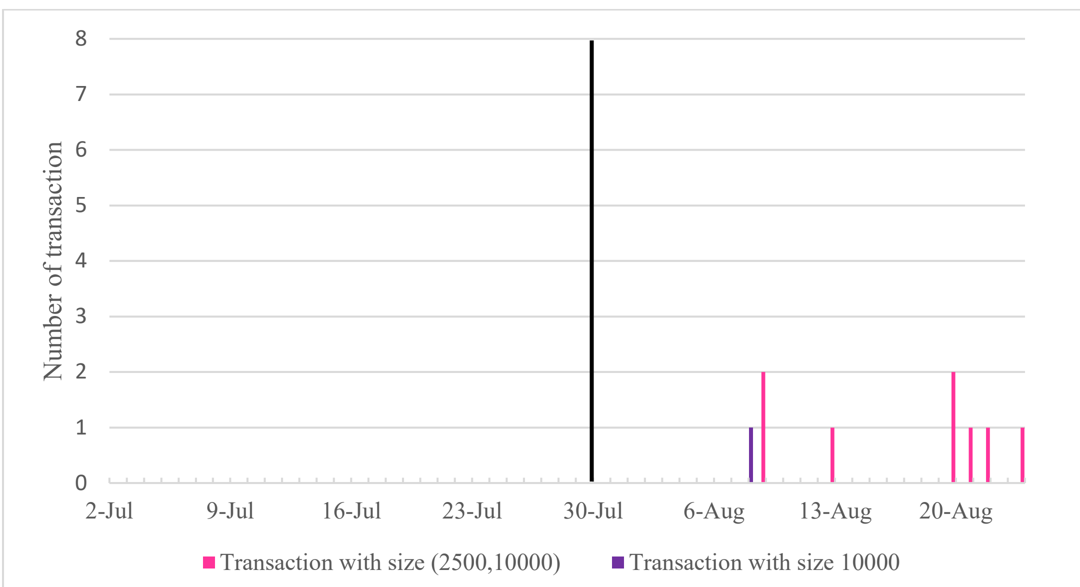
Notes: This table reports the t-test for the market quality for 20 days of pre and post rule change period. We use bootstrap t-test with 1,000 draws.

Figure 1. Number of Large Transactions in the Corn Calendar Spread Market

Panel A: Transaction with size [2,000, 2,500) and size 2,500



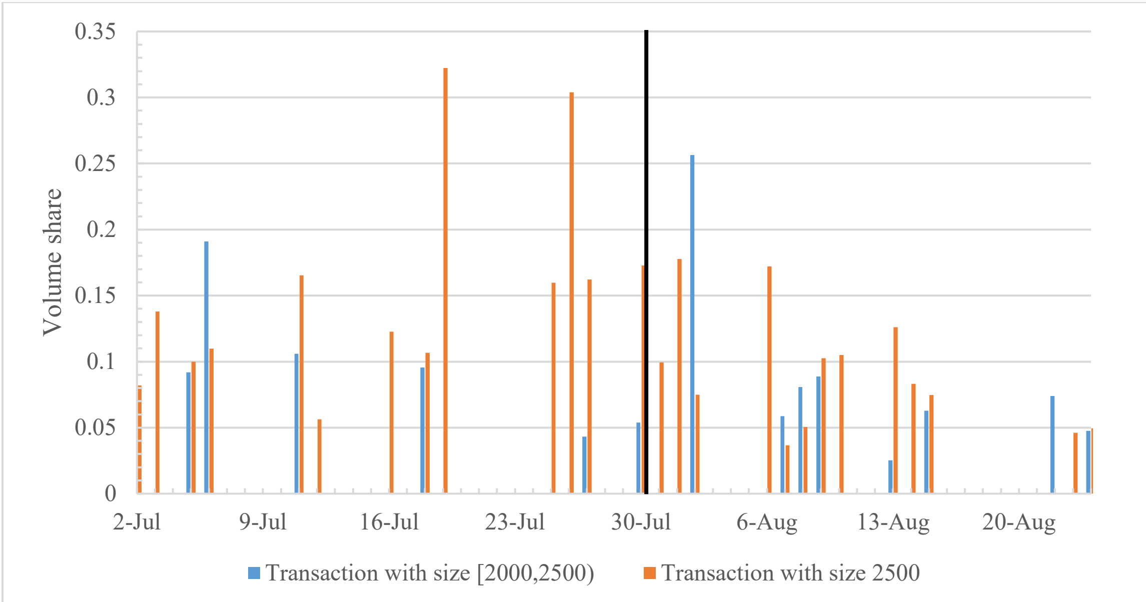
Panel B: Transaction with size [2,500, 10,000) and size 10,000



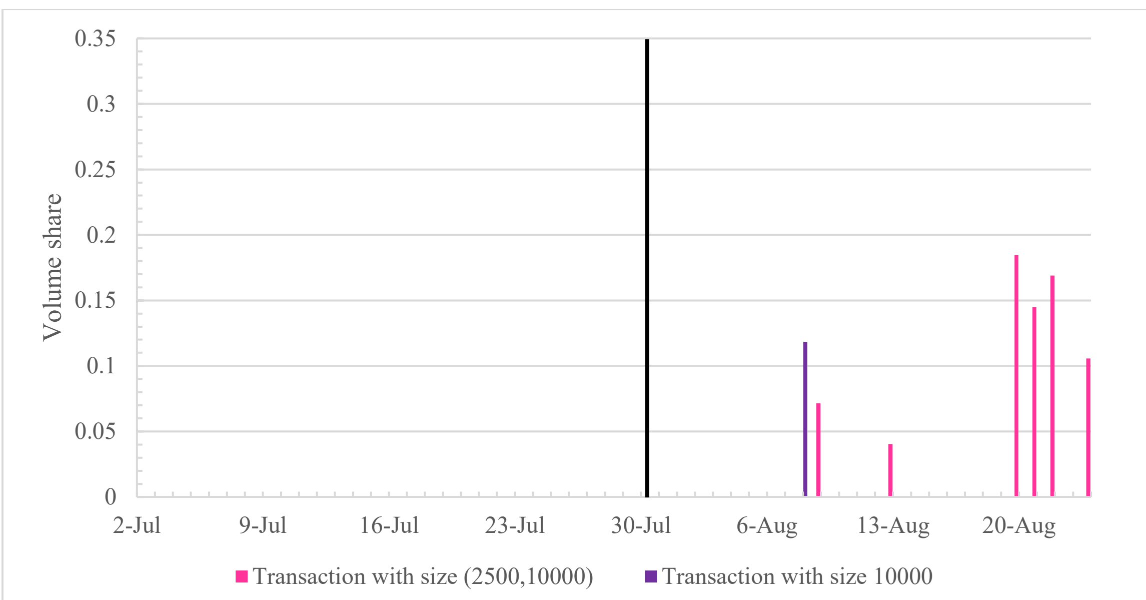
Notes: Figure 1 shows the number of large transactions in corn calendar spread futures contract ZCU8-ZCZ8 from July 2, 2018 to August 24, 2018. Panel A shows the transactions with size [2,000, 2500) and size equals to 2,500 (maximum order size before the rule change). Panel B displays the transactions with size [2,500, 10,000) and size equals to 10,000 (maximum order size after the rule change). The black vertical line denotes commencement of the rule change date July 30, 2018. CME contract symbols: H(MAR), K(MAY), N(JUL), U(SEP), Z(DEC); ZC stands for CBOT corn futures; 8 (9) indicates the year of 2018 (2019).

Figure 2. Volume Share of Large Transactions in Corn Calendar Spread Futures Market

Panel A: Transaction with size [2,000, 2,500) and size 2,500



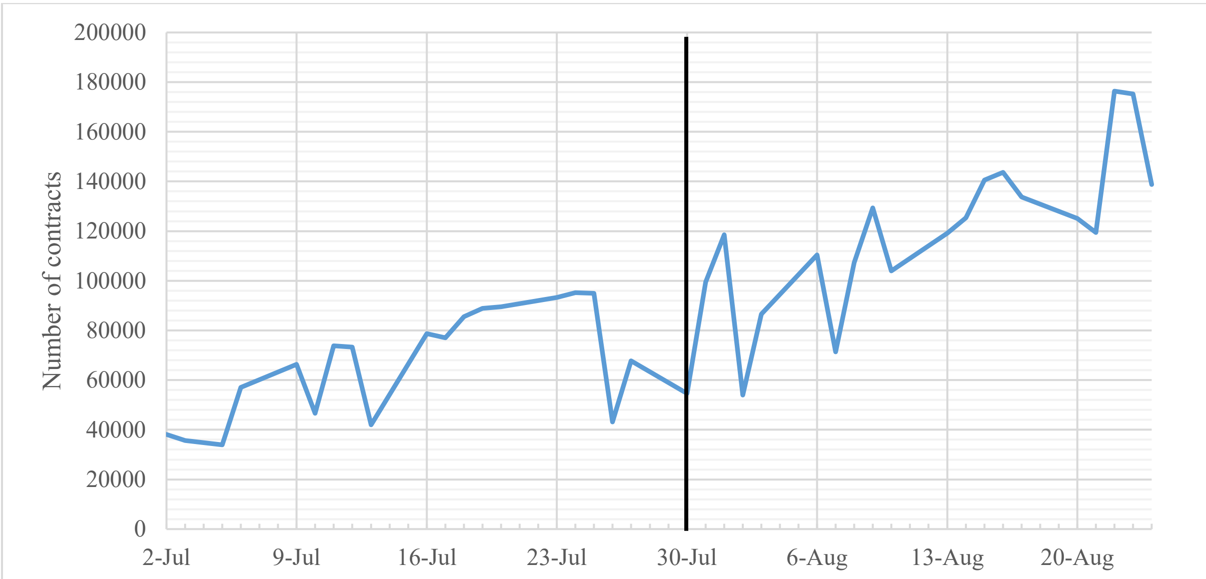
Panel B: Transaction with size [2,500, 10,000) and size 10,000



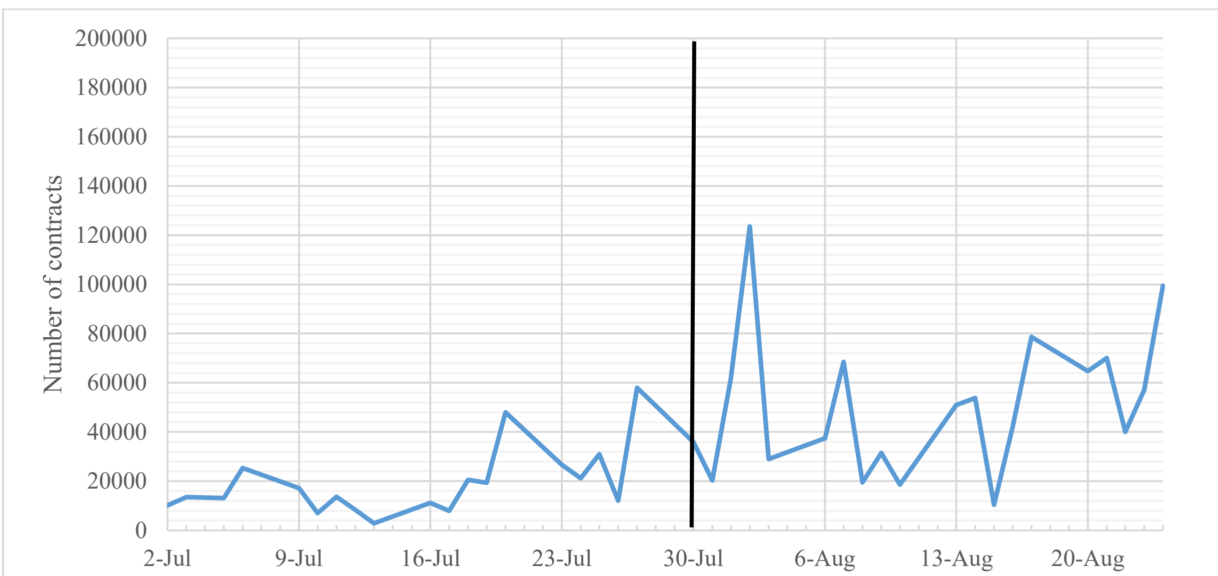
Notes: This figure shows the volume share of large transactions in corn calendar spread futures contract ZCU8-ZCZ8 from July 2, 2018 to August 24, 2018. Panel A shows the transactions with size [2,000, 2500) and size equals to 2,500 (maximum order size before the rule change). Panel B displays the transactions with size [2,500, 10,000) and size equals to 10,000 (maximum order size after the rule change). The black vertical line denotes commencement of the rule change date July 30, 2018. CME contract symbols: H(MAR), K(MAY), N(JUL), U(SEP), Z(DEC); ZC stands for CBOT corn futures; 8 (9) indicates the year of 2018 (2019).

Figure 3. Share-Weighted Depth at the Best Did and Ask

Panel A. Best Bid Depth

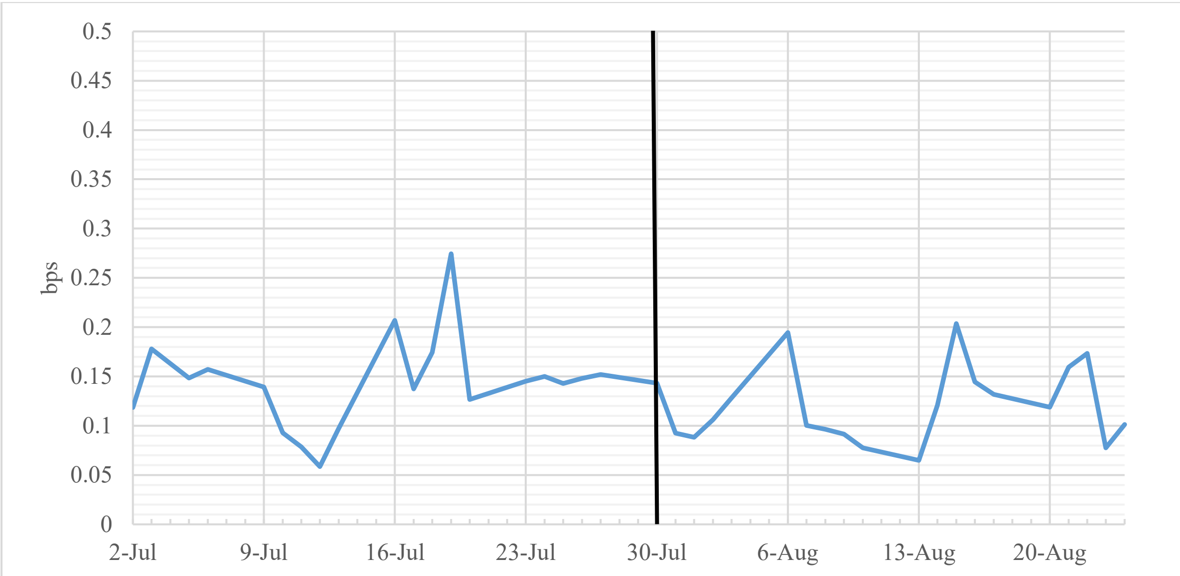


Panel B. Best Ask Depth



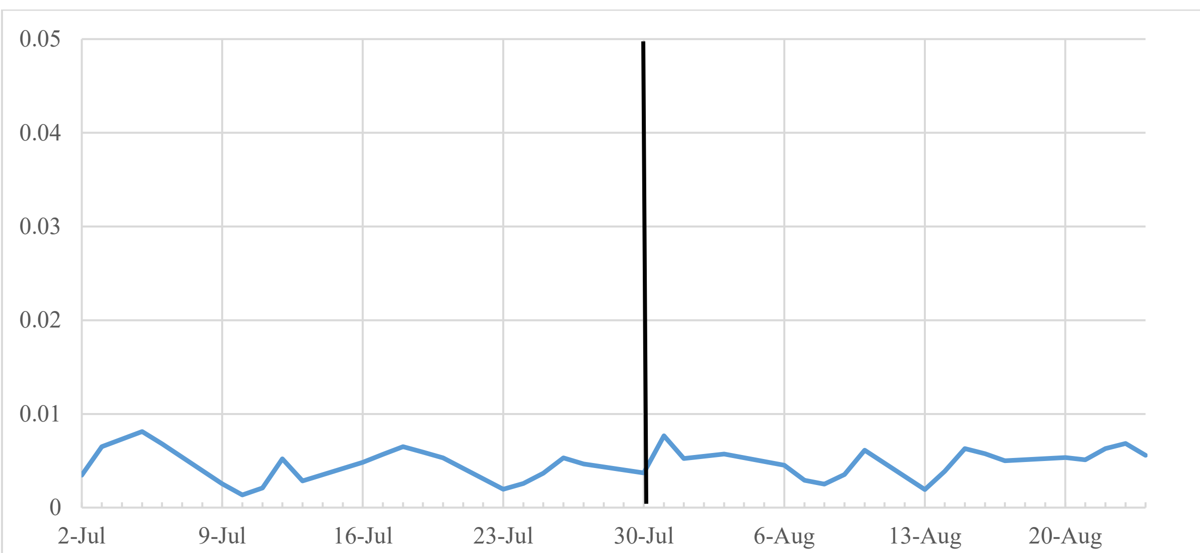
Notes: This figure shows the volume weighted daily average of the best bid depth and best ask depth for the most traded five corn futures spread contracts. A corn calendar spread futures contract involves two 5000-bushel corn outright futures contracts. The sample period is from July 2, 2018 to August 24, 2018, with trading hours from 8:30 am to 13:20 pm Central Time. The black vertical line denotes commencement of the rule change date July 30, 2018.

Figure 4. Volume Weighted Effective Spread



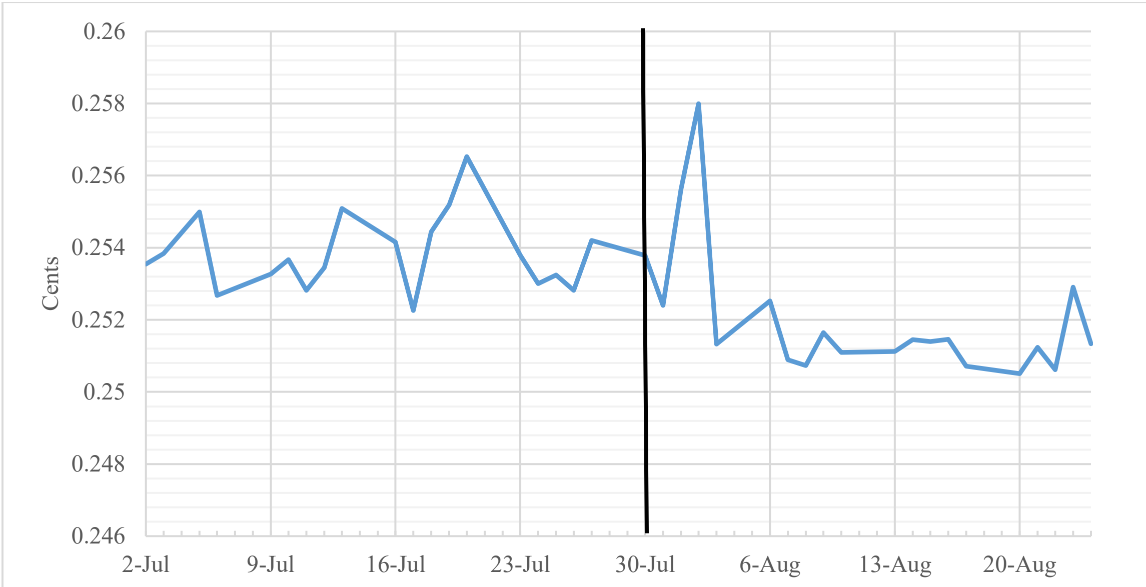
Notes: This figure shows the volume weighted daily average of the weighted effective spread (in bps) for the most traded five corn futures spread contracts. The sample period is from July 2, 2018 to August 24, 2018, with trading hours from 8:30 am to 13:20 pm Central Time. The black vertical line denotes commencement of the rule change date July 30, 2018.

Figure 5. Volume Weighted Realized Volatility



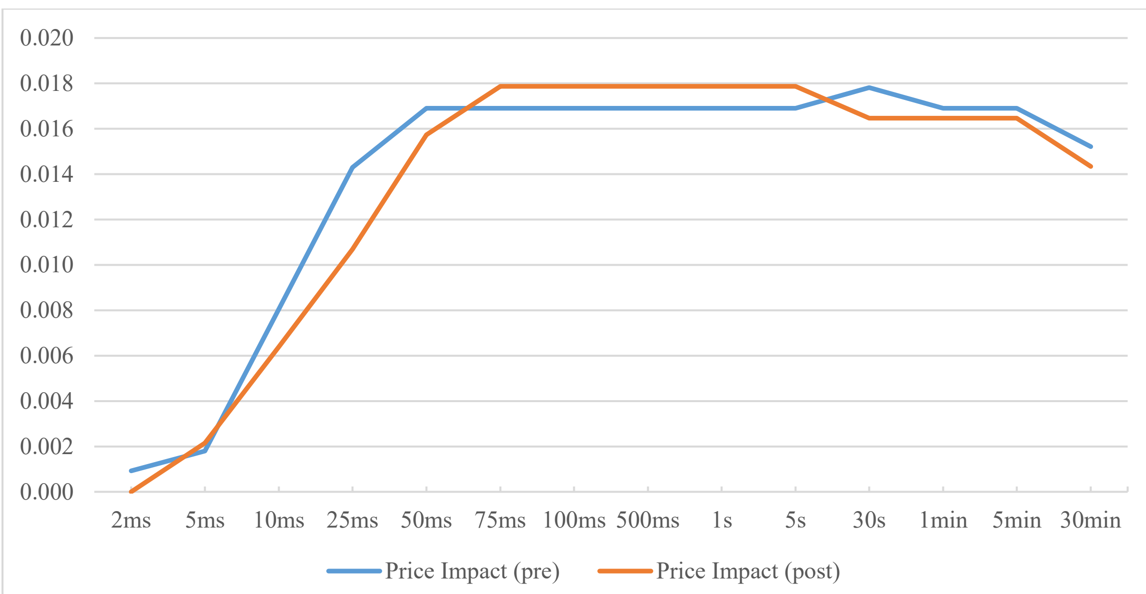
Notes: This figure shows the volume weighted daily average of the realized volatility for the most traded five corn futures spread contracts. Realized volatility is calculated as the sum of squares of all five-min price returns. The sample period is from July 2, 2018 to August 24, 2018, with trading hours from 8:30 am to 13:20 pm Central Time. The black vertical line denotes commencement of the rule change date July 30, 2018.

Figure 6. Volume Weighted Bid-Ask Spread



Notes: This figure shows the volume weighted daily average of bid-ask spread for the most traded five corn futures spread contracts. The sample period is from July 2, 2018 to August 24, 2018, with trading hours from 8:30 am to 13:20 pm Central Time. The black vertical line denotes commencement of the rule change date July 30, 2018.

Figure 7. Average Price Impact of Trade with Size 2,500 in ZCU8-ZCZ8



Notes: This figure shows the average price impact following trade with size equal to 2,500 contracts for 20 days pre and post rule change period. Pre rule change period is from June 29, 2018 to July 27, 2018, and post rule change period is from July 30, 2018 to August 24, 2018. ZCU8-ZCZ8 is the most traded contract during the period. CME contract symbol: H(MAR), K(MAY), N(JUL), U(SEP), Z(DEC), ZC stands for CBOT corn futures, and 8 (9) indicates year 2018 (2019).