NCCC-134
APPLIED COMMODITY PRICE ANALYSIS, FORECASTING AND MARKET RISK MANAGEMENT

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Suggested citation format:
Peng, K., Z. Hu, M. A. Robe, and M. K. Adjemian. 2021. "Canary in the Coal Mine: COVID-19 and Soybean Futures Market Liquidity." Proceedings of the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. [http://www.farmdoc.illinois.edu/nccc134].

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Paper prepared for the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management, 2021.

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Canary in the Coal Mine: COVID-19 and Soybean Futures Market Liquidity

We document the impact of the early stages of the COVID-19 pandemic on liquidity in U.S. agricultural markets. Notably, we show that soybean futures-market depth collapses weeks before the U.S. financial markets' crash of March 2020. Soybean futures liquidity is affected the earliest, the most, and the longest. Soybean depth drops by half for outright futures and by over 90 percent for calendar spreads, and soybean bid-ask spreads increase significantly. This liquidity pullback starts on the night of February 12 to 13, 2020—a full two weeks before (i) liquidity evaporates in U.S. bond and equity markets and (ii) soybean prices start to fall sharply. The start of the soybean liquidity pullback coincides with overnight news of bleak COVID-19 developments in China (a dominant source of world demand for oilseeds). Following a series of emergency interventions by the U.S. Federal Reserve in March and April 2020, liquidity recovers in the soybean outright futures market—but depth remains abnormally low for calendar spreads. These patterns cannot be explained by other factors, such as seasonalities or changes in soybean futures trading volume and price volatility: the COVID-19 shock was novel, and it destroyed soybean-market liquidity in a way that foretold financial-market developments two weeks later. In contrast to soybeans, we find little evidence of a drop in corn or wheat futures liquidity until U.S. financial and crude oil markets sink in early March. Soybeans were truly the canary in the coal mine.

Keywords: COVID-19, Financial market liquidity, Agricultural commodities, China, Precursor.

1. Introduction

In early March 2020, U.S. equity and bond markets began to incorporate expectations about the COVID-19 pandemic's harmful impact on the U.S. economy. Equity prices collapsed, the VIX "fear index" spiked, and liquidity providers pulled back sharply from equity and bond markets. In response, between March 17 and April 9, 2020, the U.S. Federal Reserve took unprecedented steps to shore up financial markets and restore liquidity. By late April, equity prices and bond liquidity had largely returned to their late-February levels and the VIX spike had mostly dissipated.[1]

In this paper, we investigate the impact of the early stages of the COVID-19 pandemic on liquidity in U.S. agricultural futures markets. We do so for two reasons. First, for agricultural economists, the question is critical in and of itself. Those markets have for decades been "ground zero" for worldwide food price discovery, and they are central to the ability of commercial market participants (farmers, grain elevators, processors, commodity merchandisers, feedlots,…) to hedge against commodity price risk. Reduced futures market liquidity means that price risk management entails significantly higher costs. As such, our findings are of first-order importance to a sector of the physical economy that is vital to the food supply chain.

Second, bad news about COVID-19 started to arrive (from China and then Europe) weeks before U.S. equity and bond markets recognized that there would be a pandemic—a reckoning that was not only sudden but also late when measured by official pronouncements.[2] For financial

[1] For detailed analyses of stock market performance in the first four months of 2020, see, e.g., Alfaro *et al*. (2020), Cox, Greenwald, and Ludvigson (2020), Gormsen and Koijen (2020), and Ramelli and Warner (2020). For studies of bond market liquidity during the same period see, e.g., Kargar *et al*. (2020) and O'Hara and Zhou (2020).

[2] Even U.S. hotel stocks, which one would expect to have been particularly exposed to COVID-19 developments, did not substantially underperform the U.S. stock market until early March, 2020 (Carter *et al*., 2021).

economists, a natural question is whether any U.S. market played the role of "a canary in the coal mine." The soybean futures market is the obvious candidate. China is a key source of demand for U.S. soybeans, so shocks to the Chinese domestic economy should intuitively impact the soybean market more than U.S. equity or other agricultural markets (like corn or, especially, wheat). If so, then soybean futures price dynamics and market liquidity should be impacted as soon as COVID-19 news from Asia and Europe becomes alarming. What is not obvious, are the timing and extent of that impact (*i.e*., whether it was prescient and/or exceptional).

Our paper documents the market liquidity effects of the start of the pandemic. We utilize comprehensive CBOT intraday message data for the first six months of 2020, in order to obtain granular information on all limit order book (LOB) updates for corn, soybean, and wheat futures.[3] We then carry out a series of difference-in-difference analyses. Because exchange rules on order placement and execution changed drastically in July 2018, we use 2019 for reference. We match each trading day and week in the first half of 2020 with the corresponding day of the corresponding week in 2019, and we construct benchmarks for "normal" market activity against which we can evaluate liquidity developments during the pandemic. Doing so allows us to control for seasonality and day-of-the-week effects that are commonly observed in agricultural derivatives markets. In addition, to further rule out the possibility that differences between 2020 and 2019 could be due to factors other than COVID-19, we also carry out placebo tests using data from 2016 and 2017.

Our analysis explicitly accounts for the fact that a large fraction of all commodity futures market activity takes the form of calendar spreads, *i.e*., entails simultaneously taking long and short positions in futures with different maturities (rather than trading a single maturity outright)—see Robe and Roberts (2019). Precisely, we investigate liquidity in the outright futures markets for grains and oilseeds *and* in the related calendar spread markets. To that effect, we use the CBOT message data to reconstruct the consolidated LOB for the calendar spread and outright markets.

We find that the onset of the COVID-19 pandemic hurts liquidity (quoted bid-ask spreads and top-of-the-book depth) in the three largest U.S. grains and oilseeds futures markets. Unlike in financial markets, however, not all these developments wait until early March. The soybean market depth drops significantly starting during the night of February 12 to 13—coinciding with reports of a ten-fold increase in Chinese COVID-19 cases. We find very large soybean depth drops in both the outright and calendar spread markets, and in the daytime and overnight sessions. This liquidity pullback is especially noticeable for calendar spreads: compared to the pre-COVID period, top-of-the-book soybean depth falls by approximately half for outright futures but by more than *ninety* percent for calendar spreads (in both day and overnight sessions). In contrast, the timing of the corn and wheat liquidity decreases follow (rather than lead) liquidity developments in financial markets. These findings are consistent with the fact that China is by far the world's largest oilseeds importer and, hence, Chinese demand is more critical for soybeans than for corn or wheat.[4]

Because soybean futures are impacted much earlier (and at least as much as or more) than corn and wheat futures, we further investigate liquidity in the soybean futures market in order to assess the extent to which the COVID-19 crisis was unusual. First, we show that, at the same time that depth quoted at the top of the book drops dramatically, large-size calendar spread trades (2,500

[3] The LOB is a record of all outstanding limit orders on an exchange at any point in time, where limit orders represent the desire to buy or sell an asset at a specific price or better.

[4] To wit, the U.S. government projects that China will import 60% of globally traded soybeans in the 2020/21 marketing year, with far smaller figures for corn (9.9%) and wheat (4.8%)—see USDA (2021).

contracts and above)—which used to make up a substantial share of the total trading volume until February 12, 2020—virtually vanish from our sample soon after that date. Next, we run difference-in-difference analyses of bid-ask spreads and top depth (defined as the number of contracts bid or offered at the best quotes), using 2019 as a benchmark to control for seasonalities in the soybean market.[5] We find that, on average in the period from February 13 to April 9, 2020, bid-ask spreads jump by five percent in the day session, and by six (outright futures) to eleven (calendar spreads) percent in the night session. Finally, we show that soybean futures liquidity generally, and depth particularly, drops over and above what is attributable to changes in trading volume or in price volatility during that period. Furthermore, while outright futures depth recovers after April 9, calendar-spread depth still had not recovered by the end of June 2020. Altogether, our findings establish that the onset of the COVID-19 crisis amounted to a unique shock to the soybean market that foreshadowed its effect on the wider economy.

Our paper is at the intersection of the fast-growing financial and agricultural literatures on the impact of COVID-19. The agricultural economics studies closest to ours focus on physical-market reactions after the first COVID-19 cases in the United States. For example, Mallory (2021) finds that U.S. and Brazilian exports of meat were impacted in the medium-term whereas exports of grains and oilseeds were not, while Schnitkey *et al*. (2020) find depressed returns to Midwestern corn and soybean farmers during the first half of 2020. We complement those studies by investigating liquidity provision in futures markets, where farmers and exporters can hedge their price risk. We show that the start of the COVID-19 crisis was a one-of-a-kind shock to the soybean market. Futures liquidity dropped substantially, pushing up commercial market participants' hedging costs—both by curtailing the propensity of traders to place large market orders and by significantly increasing the cost of executing smaller orders.

Our paper also contributes to two strands of the financial economics literature. First, we show that top-depth reacts to the uncertainty stemming from COVID-19 much more strongly than bid-ask spreads do. This finding complements evidence that, in equity markets, liquidity providers should (Kavajecz, 1999; Dupont, 2000) and do (Fishe and Robe, 2004; Goldstein and Kavajecz, 2006) use depth to manage their risk during information-rich events. Second, our paper is the first to investigate commodity-market liquidity at the start of COVID-19. Research in equity markets looks mostly at the impact of COVID-19 and of the subsequent policy responses on stock prices.[6] Our endeavor is thus closer to a set of studies in the fixed-income space that investigate the effect of COVID-19 on market liquidity. Kargar *et al*. (2020) focus on corporate bonds: they find that liquidity costs rose in mid-March 2020 as selling pressure surged, and that liquidity provision improved after a series of Federal Reserve interventions. Similar liquidity dynamics are also found in other compartments of the U.S. fixed-income market during the first half of 2020—U.S. Government bonds (Ermolov, 2020) and Treasury Market (Fleming, 2020). We show that depth in a major agricultural futures market played a leading role in reflecting COVID-19 news, a full two weeks before U.S. financial markets (or other U.S. agricultural markets) recognized the

[5] Changes by the CME in 2018 of its maximum-order size and order-execution rules make it hard to compare liquidity patterns in 2019 and 2020 with earlier years. Still, robustness checks with 2016-2017 data support our conclusions.

[6] For example, Mamaysky (2020) uses a newspaper-based measure of news related to COVID-19 to argue that major financial markets "overreact" to news about COVID-19 between January and mid-March 2020. Baker *et al*. (2020) complement this finding by documenting that, in the early phase (February 24 to March 24, 2020) of the COVID-19 pandemic, "large" equity movements (defined as price changes greater than 2.5%) in the U.S. stock market can be mostly attributed by newspapers to news about COVID-19. See also Alfaro *et al*. (2020), Cox, Greenwald, and Ludvigson (2020), Gormsen and Koijen (2020), and Ramelli and Warner (2020).

severity of the pandemic. U.S. soybean futures played the role of canary in the coal mine: the magnitude of the depth drop in that commodity market in mid-February foretold the impact of the COVID-19 shock on U.S. markets and on the U.S. economy in early March.

The remainder of the paper proceeds as follows. Section 2 discusses our data. Section 3 provides a graphical analysis of top-of-the-book depth for corn, wheat, and soybeans that motivates focusing the rest of the paper and our econometric analysis on soybean liquidity. Section 4 discusses our empirical approach and summarizes our regression results. Section 5 concludes. Two appendices complete the paper.

2. Data

The data we use are drawn from the CME Group's Market Depth by Price (MDP) dataset for CBOT electronically-traded corn, soft red winter (SRW) wheat, and soybean futures. For each commodity, the MDP dataset covers outright futures and calendar spreads of futures. Our sample runs from January 14 to June 26 in 2019, and from January 13 to June 24 in 2020. In addition, for the robustness checks, we also use similar data from the first six months of 2016 and of 2017.

The CME Globex regular trading hours run from 8:30 a.m. to 1:20 p.m. U.S. Central Time (CT), Monday to Friday. The night trading hours run from 7:00 p.m. to 7:45 a.m. CT, Sunday to Friday. The night session is usually ignored in the literature due to the perception that the "after-hours" trading volume is fairly low in agricultural futures markets—see, e.g., Janzen and Adjemian (2017), Arzandeh and Frank (2019), and He, Serra, and Garcia (2021) for recent examples of that approach. However, the night session is important in our study because the time when COVID-19 related information shocks from overseas occur is during Asian (at the beginning of the pandemic) or European (soon thereafter) business hours, *i.e.*, during the U.S. night trading session. We therefore run all our analyses for both the day and the night sessions.

2.1. The Year 2019 as a Benchmark

Table 1 lists key dates related to the COVID-19 epidemic and policy responses in the first half of 2020, which is the period on which we focus. We use 2019 as a benchmark to gauge the effect of the COVID-19 crisis on the agricultural futures markets in 2020, in order to control for seasonality and day-of-the-week effects that are well known in these markets—see, e.g., Anderson (1985), Brorsen (1989), Streeter and Tomek (1992), and Goodwin and Schnepf (2000).

Precisely, to construct daily measures of returns, realized volatility, and market liquidity (quoted bid-ask spreads or top-of-the-book depth), we match each trading day in 2020 with the corresponding day of the week in 2019. For example, our sample starts on Monday in the third week of January—which is the 14^{th} of the month in 2019 and the 13^{th} in 2020, respectively. We account for national holidays in both years, using the CME Globex trading schedule. This procedure yields daily benchmarks for "previously normal" trading activity against which we can evaluate market developments during the first few months of the 2020 pandemic.

Ideally, one would prefer to use a larger number of years to create a benchmark. The reason why we focus our comparisons on a single year (2019) is that the CBOT changed its maximum-order-size and order-execution rules considerably in July 2018 for corn and soybean futures.[7] As a result, comparing 2019-2020 figures directly with data from prior years might lead to biases.[8]

Still, notwithstanding our careful matching of trading days in 2020 and 2019, one might worry that some of the differences between 2020 and 2019 might stem from factors other than COVID-19. Since liquidity figures are not directly comparable before and after the exchange's Summer 2018 rule changes, we devise placebo tests using 2016-2017 data in order to rule out that possibility—see Section 4.3.d.

2.2. Reconstructing the Limit-Order Book for Outright Futures and Calendar Spreads

The CME Group's MDP data provide all electronic market message updates necessary to reconstruct the limit order book (LOB, up to ten-deep) and the trade information for both day and night trading sessions. Message updates to the LOB are time-stamped to the nanosecond and occur as orders are submitted, canceled, changed, or executed. Specifically, each LOB update contains the time, sequence, prices with the number of limit orders resting on each bid (ask) depth up to ten-depth. For each transaction, the MDP data provide the time, sequence, price, size, and the initiator associated with the trade. A trade can be initiated by either a buyer or a seller as well as classified as an implied trade when matching with implied order(s).

We reconstruct the *consolidated* LOB for all our analyses. This consolidation is necessary because updates in the LOB also reflect changes to implied orders that can be either (i) orders in the outright book created based on orders in the spread market ("implied-out") or (ii) orders in the calendar spread book created based on orders in the outright market ("implied-in").[9]

2.3. Focus on the Most-Active Contracts

Soybean futures contracts have seven maturities: January (ticker: F), March (H), May (K), July (N), August (Q), September (U), and November (X). Corn and soft red winter wheat futures have five maturities: March, May, July, and December (Z).

From January to June, the most-traded grains and oilseed futures are almost always the nearby contracts. The nearby contract has a dominant share of the total trading volume throughout our sample period—especially in the outright market. In turn, not all contract maturities that are listed on any given day generate a lot of trading volume. For this reason, for each commodity, we focus either on the most-traded (Section 3) or on the five most-traded futures contracts for outrights or

[7] The CME initially implemented its maximum-order-size rules for calendar spreads in the corn and soybean futures markets in July 2018. The changes were initially billed as experimental. They were made permanent at the end of the 2018—see https://www.cmegroup.com/notices/ser/2018/12/SER-8300.html

[8] For example, Peng, Hu, and Robe (2020) show that, after the CBOT's quadrupling of the maximum size for calendar-spread market orders (from 2,500 to 10,000 contracts), a substantial fraction of the total daily corn calendar-spread trading volume consists of trades in the 2,501-10,000 range. That finding supports the notion that the CBOT changed its rules in order to better meet the needs of large liquidity demanders—typically commercial futures traders. Amid the COVID-19 shock, though, one might expect that the execution costs of such large trades would increase significantly—potentially enough so that supersized market orders would stop being placed altogether. Such a disappearing act, however, could obviously not be observed prior to July 2018—regardless of whether a major shock to market fundamentals had taken place or not.

[9] Arzandeh and Frank (2019) describe how to reconstruct the consolidated LOB in agricultural futures markets.

contract pairs for spreads (Section 4). For outright futures *(resp. calendar spreads),* the "top-five" contracts make up 94%-96% *(resp. 70%-84%)* of the total volume across all active outright *(resp. calendar spreads)* contracts.[10]

We roll over the "nearby" contract to the next maturity the day before the "first position" day (which is two business days before the start of the delivery month). This procedure amounts to dropping the prompt contract from the sample in the first two weeks of the contract month. It circumvents issues related to the fact that spot-month position limits apply to non-commercial traders during the delivery period (with the result that many traders need to trim or close their positions before the first position day, possibly resulting in unusual liquidity and price volatility).

2.4. Volume-Weighted Measures

For a number of our analyses in Section 4, we compute daily measures of market prices, volatility, and liquidity (bid-ask spreads and top-of-the-book depth) using weighted averages based on the daily trading volume of the five most-traded contracts contract. For each day in our sample period, Tables A1 (for 2019) and A2 (for 2020) in Appendix 1 list the set of the five most-traded contracts: we keep this set constant for two months at a time—as noted above, we redefine the "nearby" futures at the end of February and again at the end of April. We compute the weights separately for the day and night sessions.

The top depth (defined as the number of contracts bid or offered at the best quotes) is the daily volume-weighted average of the sum of the best bid and best ask depths for the five most-traded contracts. We first compute the top depth for each of the top-most-traded contracts, using the simple daily session averages of the sums of the bid and ask depths posted at the inside quotes, and then we compute daily volume-weighted averages of the contract-level figures across the top-five contracts. We proceed similarly for the bid-ask spread (which is measured in cents per bushel) and for realized volatility (using the sum of squares of five-minute non-overlapping returns). For all variables, we compute daily volume-weighted averages separately for outrights and for calendar spreads, and for the day and the night sessions.

3. Depth in the Soybean *vs.* the Corn and the Wheat Futures Markets

In this Section, we perform a graphical analysis of the top-of-the-book depth in the three largest U.S. futures markets for oilseeds and grains. For this initial investigation, we focus on the most-traded contract in each market: the nearby contract in the case of outright futures, and the nearby/first-deferred pair of contracts in the case of calendar spreads.

Figure 1 plots the top depth from January through May 2020 for each market. It is immediately apparent that depth in the corn market (Panel A) and, especially, in the SRW wheat market (Panel B) drops significantly later than soybean depth does (Panel C). This fact holds for outright futures as well as for calendar spreads.[11]

[10] Tables A1 and A2 in the Appendix provide the shares of the trading volume of the five most-traded contracts. The three most-traded contracts are the same in both years. Although the 4th or 5th most-traded contracts differ across our sample years on some trading days, this potential issue is mitigated by the fact that the aggregate volume share of those two contracts is small: less than 9% on average.

[11] In the same vein, Vercammen (2020) finds that wheat prices and basis do not change significantly till March 2020.

The difference in the timing of the three depth decreases is striking. Corn depth only craters at the beginning of March, *i.e*., when liquidity starts to evaporate in the U.S. bond markets (Kargar *et al*., 2020; O'Hara and Zhou, 2021). Depth in the SRW wheat market waits even more to drop—a full week more, until March 12.[12] In contrast to corn and wheat futures, however, soybean futures depth plunges starting during the night of February 12 to 13, 2020—which coincides with news of a ten-fold increase in the number of COVID-19 cases in China. The soybean depth drop not only happens early (compared to both financial markets and other agricultural futures markets), but it is also very large: Panel C in Figure 1 shows that nearby depth falls by half in the outright market, and by more than 90 percent in the calendar spread market, in the last two weeks of February.

A natural question is whether this early, substantial drop in soybean market liquidity is accompanied by large contemporaneous price changes. Figure 2 shows otherwise. It plots the nearby soybean futures price (Panel A) and the annualized soybean cost-of-carry factor (computed using the slope of the term structure of futures prices, averaged across the three most active calendar spreads, Panel B) in the first halves of 2020 and 2019. Panel C of Figure 2 plots the number of COVID-19 deaths during the first half of 2020.

In the first four months of 2020, the volatilities of both the outright and the calendar spread prices are clearly higher than during the corresponding period in 2019. The picture is more mixed for the daily average price levels. On the one hand, Panel B in Figure 2 shows that the daily average calendar spread prices (whose biggest component is the cost of storage net of convenience yield) start to trend up starting in mid-February, around the same time that posted depth starts to evaporate in the calendar spread market (recall Figure 1, Panel C). On the other hand, Panel A in Figure 2 shows that, although the nearby soybean price (*i.e*., the price of the commodity itself) drops in the second half of January 2020, it then *rebound*s the next month—so that the major impact of COVID-19 on the price level of soybeans does not take place until the prices of financial assets, of crude oil, and of corn start to collapse (in the first half of March 2020).[13]

This initial analysis establishes that the timing of the liquidity developments in the soybean futures market is unique: soybean futures liquidity drops significantly a full two weeks ahead of liquidity in other U.S. agricultural markets, and two weeks before the soybean prices start to fall. We therefore focus Section 4 on soybean liquidity—for both outrights futures and calendar spreads.

4. The Impact of COVID-19 on Liquidity Provision in the Soybeans Futures Market

As described in Section 2, our strategy to identify the impact of COVID-19 on liquidity in the U.S. soybean futures market involves studying the difference in trading volume, volume share of large trades, volatility, bid-ask spread (BAS), and depth between 2020 and a benchmark year (2019), in order to control for seasonal patterns and day-of-the-week effects in trading activity. Specifically, we match the year 2020 with our benchmark year (2019); after carefully matching on trading day

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[12] The fact that depth drops less for wheat calendar spreads than for corn or soybean is most likely explained (at least in part) by significant differences in maximum-order-size and order-execution rules for wheat futures as opposed to corn and soybean futures—see Peng, Hu, and Robe (2020).

[13] Once the COVID-19 crisis starts for soybeans, Figure 2 shows that both outright and calendar spread prices are much more volatile in 2020 than in 2019. We will return to this fact in Section 4.

attributes, we analyze differences in the outcomes of interest below to estimate the impact of the pandemic. In addition, we run placebo tests using 2016-2017 data (Section 4.3.d).

4.1 *Comparing 2020 against a benchmark*

To compare market activity in 2020 against the benchmark year, we generate log ratios for the variables of interest (volume, volatility, top-of-the-book depth or "top depth," and bid-ask-spread or "BAS") in the former *vs*. the latter. For a variable *X*, on matched trading day *t*, we define $lnRatio\_X_t$ as the logarithm of the values takes on by that variable in 2020 and in 2019:

$$lnRatio\_X_t = \ln\left(\frac{X_{2020,t}}{X_{2019,t}}\right), \qquad (1)$$

Ratios with values greater *(resp. smaller)* than zero therefore imply that *X* in 2020 was larger *(resp. smaller)* than *X* in 2019; for small changes, the value approximates a percent difference.

4.2 *Volume, Volatility, and Liquidity in the Soybean Market: A Graphical Analysis*

4.2.a. Trading volume

Figure 4 shows the total trading volume of the five most-traded contracts, as well as the natural logarithm of the ratio of those trading volumes in 2020 and 2019, for both outright and calendar spread markets during our sample period. As expected, the volume in the day session is generally higher compared to the night session for both markets in both years. Interestingly, the trading volumes in 2020 are broadly similar to their 2019 counterparts.

4.2.b. Realized volatility

For each trading day, we calculate the five-minute non-overlapping realized volatility (RV) for each contract and use the volume shares of the five most-traded contracts to generate volume-weighted results. We define the weighted-average realized volatility RV_t on trading day *t* as the sum of squares of price changes $y_{t,j}$ over each five-minute interval *j*:

$$RV_t = \sum_{i}^{5} w_{i,t} \sum_{j=1}^{J} y_{t,i,j}^2, \qquad (2)$$

where $w_{i,t} = \frac{vol_{i,t}}{\sum_i^5 vol_{i,t}}$ is the volume weight of contract *i* among the five most-traded contracts on day *t*. Each trading day has *J*=58 *(resp. 153)* five-minute intervals during the 290 *(resp. 765)* minutes of regular or "day" trading hours *(resp. night session)*.[14]

Panel A *(resp. Panel B)* in Table 2 gives summary statistics for the volume-weighted soybean RV in the first half of 2019 and the first half of 2020 for outright futures *(resp. calendar spreads)*. Comparing the corresponding figures in these two tables, RV is much higher for outrights than for calendar spreads. Intuitively, a commodity's cost-of-carry factor does not change as much as its

[14] We use the untransformed price level (as opposed to the natural logs) as there exist zero price values in calendar spread markets given that the futures curve alternates between contango and backwardation in our sample period (and the natural log of zero is undefined).

price level does. Tables 2 and 3 also show that the night session has higher average volatility in 2020—for both outright and calendar spread markets.[15]

Comparing the first halves of 2019 and 2020, however, we see very different average RV changes for outrights *vs*. calendar spreads. On the one hand, the mean RV of calendar spread prices (Table 2B) more than doubles year-over-year, from 1.34 cents squared per bushel ("cspb") in the first half of 2019 to 3.11 cspb in the first half of 2020 *(resp. 1.05 to 2.25 cspb)* during the day *(resp. night)* session—which is an increase of 132.09% *(resp. 114.29%)*. On the other hand, the mean RV of outright prices only increases by 28.9% (from 27.57 cspb in 2019 to 35.26 cspb in 2020) for the night session, and it *drops* by 16.7% (from 48.08 to 41.99 cspb) in the day session. Why?

To find the answer, Figure 5 plots the daily weighted-average RV (and also the log ratios comparing 2020 and 2019) for the outright and calendar spread markets in our sample period. The figure shows that, once the severity of the COVID-19 pandemic in China becomes clear (starting in the night session of February 12-13), the soybean-market RV moves higher than it was the year prior. Specifically, relative soybean volatility (captured by the log ratio) rises from February 13, 2020 for both outright and calendar spread markets, in both day and night sessions, peaking in mid-March. Then, soybean RV decreases at the end of March following market interventions by the U.S. Federal Reserve. The log ratios in Panels C and D of Figure 5 highlight these trends.

If COVID-19 drove up RV from mid-February to early April in 2020, then what drove up RV in much of May and June of 2019? The elevated volatility in late spring 2019 was driven by record precipitations and flooding, which delayed planting and generated big uncertainties and price fluctuations in the soybean market (Schnitkey and Zulauf, 2019; Hubbs and Irwin, 2019). This fact is interesting in itself: the 2020 COVID-19 crisis impacted the calendar spread market much more than the outright market, and the night session more than the day session—whereas the opposite is true for the 2019 Midwest floods. The same fact also raises a key question—whether similar increases in intraday RV amid COVID-19 (a type of market shock unseen for more than a century) *vs*. floods (a more frequent phenomenon) were accompanied by similar or by different liquidity reactions. We answer this question next.

4.2.c. Liquidity

We calculate two measures of market liquidity: the top-of-book depth ("top depth") and the bid-ask spread ("BAS"). The top depth, calculated as the sum of the total number of limit orders in the LOB at the best bid and ask prices, represents the liquidity available to market participants for immediate execution. The BAS, defined as the difference between the best bid and ask quotes, is a measure of transaction cost for small orders.[16]

For each trading day, we construct volume-weighted depth and BAS measures. For the day and the night sessions, we first calculate the daily simple averages of the top depth and BAS for each

[15] The elevated RV in the night-session might be an indication of possible information shocks from overseas amid the COVID-19 pandemic. Alternatively, it might reflect a greater relative impact amid COVID of trades by market participants who use the night session to rebalance their inventory.

[16] We do not consider other traditional liquidity measures such as the effective bid-ask spread because the prices in the calendar spread market can be close or equal to zero as the market alternates between contango and backwardation in our sample; this fact poses problems for liquidity measures that specify price (or mid quote) as a denominator.

of the five most-traded contracts,[17] and then use the volume shares of the contracts to calculate weighted averages. The daily volume-weighted depth ($Depth_t$) and BAS (BAS_t) on trading day *t* (either for the day or the night trading session) can be expressed as follows:

$$Depth_t = \sum_{i}^{5} w_{i,t} \frac{\sum_{n=1}^{N}(Bid\_depth_n + Ask\_depth_n)}{N_t}, \qquad (3)$$

$$BAS_t = \sum_{i}^{5} w_{i,t} \frac{\sum_{n=1}^{N}(Ask_n - Bid_n)}{N_t}, \qquad (4)$$

where *i*=1,…,5 indexes the top-five most-traded contracts; *n*=1,2,3…, *N* represents the *n*th update in the LOB; and $w_{i,t}$ is the volume share for the i^{th} contract on day *t*.[18]

Tables 2 and 3 summarize the volume-weighted top depth and BAS for soybean outrights and calendar spreads, and for the day and the night sessions, during our sample period. As expected, the day session exhibits better average liquidity than the night session does: the day-time top depth (*BAS*) is always larger (*smaller*) than its overnight counterpart.

More importantly given the present paper's objective, Tables 2 and 3 show remarkably different market liquidity evolutions for calendar spreads *vs*. outrights. In many ways, these differences echo the RV patterns discussed in Section 4.2.b.

For outrights, the BAS is—on average for the first full six months of each year—essentially unchanged. The top depth is actually higher in 2020 than in 2019 for outrights—rising from 103 to 109 *(resp. 43 to 48)* contracts in the day *(resp. night)* session.

For calendar spreads, in contrast, liquidity is on average much worse in 2020 than in 2019. First, the mean calendar spread BAS rises in both the day (+3.36%) and night (+8.24%) sessions. Second, depth drops massively. Specifically, the calendar spread top depth drops from an average of almost 91 thousand contracts (bid plus ask depth) in 2019 to just 7,914 contracts in 2020. The disappearance of more than 90 percent of the posted depth is all the more remarkable that these figures are sample averages and thus include a pre-COVID period in 2020.

Figure 6 plots the volume-weighted depth at the top of the book for the five most-traded contracts in 2019 and 2020 for both outright and calendar spread markets, as well as the log ratios of the depth in 2020 and 2019. Figure 6 allows us to time the precise moment when depth starts to contract considerably: on the night of Feb 12 to 13, 2020. The figure also shows that, following a series of Federal Reserve interventions from March through April 9, 2020, outright-market depth recovers. However, calendar-spread depth remains depressed throughout our sample period.

Figure 7 plots the evolution of the daily volume-weighted average BAS in both markets in our sample period. In general, the night-session BAS is higher than its day-session counterpart, which is consistent with the notion that daytime markets should exhibit better liquidity than after-hours

[17] In robustness checks, we perform an analysis using the time-weighted measure. Explicitly, we use the time length during which one value of depth *(resp. BAS)* sits in the LOB as the weight to calculate the time-weighted daily averages for each contract. The regressions results are similar to those with simple averages and are therefore not reported.
[18] Tables A1 and A2 in the Appendix list the weights for the top-five most-traded contracts.

markets due to greater volume. In Figure 7, the BAS begins to trend upward in mid-February especially for the night session, in both the outright and calendar spread markets. The 2020 night session—especially for the calendar spread market—displays several large spikes, indicating that the BAS increases by more than one tick (0.25 cents) and remains wide during the night session. We interpret this finding to indicate that the COVID-19 shock substantially increased the execution costs of liquidity demanders (*i.e*., hedgers who place market orders).

4.2.d. "Pre-COVID", "COVID", and "Post-Fed" Periods

Table 4 provides statistical evidence to supplement the graphical evidence of Figures 4 to 7. Specifically, Table 4 summarizes the results of pairwise t-tests of the differences between the sub-period means of the log ratios (2020 *vs*. matched-day in 2019) of our volume, volatility, bid-ask spread and depth variables in three successive period in 2020: (i) "pre-COVID", defined as January 13 through February 12; (ii) "COVID", defined as the period from the night of February 12 to 13 until April 9; (iii) and "post-Fed", defined as rest of the sample period through the end of June, following the last major Federal Reserve intervention on April 9, 2020.[19]

Table 4 shows that volume is mostly unchanged whereas RV is statistically significantly much higher, from February 13 through April 9, 2020 –compared to before or after that eight-week period. BAS increase by five percent in the day session—for both outrights and calendar spreads—and by six percent (outrights) or eleven percent (calendar spreads) in the night session. Table 4 also confirms that the magnitude of the depth decrease during the "COVID" period is truly massive, and predictably it is highly statistically significant.

4.3 Volume, Volatility, and Liquidity in the Soybean Market: A Regression Analysis

Armed with the information gathered in the previous sections, we now turn to a formal analysis of the statistical significance of futures-market liquidity developments around the first months of the COVID-19 pandemic.

4.3.a. Unit root tests

We start by testing for the orders of integration of our time series, as part of the process to determine the appropriate econometric methodology. We use the augmented Dickey–Fuller (ADF) unit root test and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test—which is more robust with a finite sample—to test for stationarity of the time series.

Table 3 summarizes the results. The ADF and KPSS tests show that the log ratios are individually $I(1)$ in nearly all cases. The ADF and KPSS tests agree about the orders of integration, except for the day-session log ratio for trading volume in the outright market, and for the day-session log ratios for the BAS and depth in the calendar spread market. Regardless, given that all the variables are either $I(1)$ or $I(0)$, we run the Dynamic Ordinary Least Squares (DOLS) model proposed by

[19] As of February 2021, the COVID-19 pandemic is ongoing, with more than a half million new cases and thousands of additional deaths reported daily. While the worst of the COVID-19 impact on financial market liquidity seems to be over, it is much too soon to talk of a "post-crisis" period. We therefore use the term "post-Fed" to describe the third sub-period.

Saikkonen (1991) and Stock and Watson (1993) as it allows using variables of different orders of integration to estimate cointegrating relationships among variables.

The DOLS approach is to estimate such relationships using a single-equation method with leads and lags for first-differenced variables in order to eliminate the effect of possible endogeneity (which is a concern when modeling liquidity using trading volume and volatility in agricultural futures markets—see, e.g., Wang, Garcia, and Irwin 2012). In addition, DOLS is a single-equation method and provides consistent estimates in a small finite sample (Stock and Watson 1993).[20]

4.3.b. Dynamic OLS Analysis: Methodology

To study the impact of COVID-19 on market liquidity, we specify the DOLS model as follows:

$$\begin{aligned} lnRatio\_liquidity_t = \\ \alpha lnRatio\_Vol_t + \beta lnRatio\_RV_t + \gamma COVID_t + \boldsymbol{\delta}'\boldsymbol{D} \\ + \textstyle\sum_{i=-k}^{k} \lambda_i \Delta lnRatio\_Vol_{t-i} + \sum_{i=-k}^{k} \delta_i \Delta lnRatio\_RV_{t-i} + \epsilon_t, \end{aligned} \quad (5)$$

where $lnRatio\_liquidity_t$ is the natural logarithm ratio (2020 *vs*. 2019) for a liquidity variable (we use $lnRatio\_BAS_t$ for the BAS and $lnRatio\_Depth_t$ for market depth). We examine separately the impacts of COVID-19 on the BAS and on depth. The right-hand side market-conditions variables $lnRatio\_Vol$ and $lnRatio\_RV$ are log ratios of the trading volume (Vol) and realized volatility (RV) as defined earlier. The effect of COVID-19's onset on the level of market liquidity is captured by the dummy variable $COVID_t$, which we set equal to one between from Feb 13 to April 9, 2020 (*i.e*., during the "COVID" sub-period chosen in Table 4) and zero otherwise.

In addition to controlling for volume and realized volatility, we control for possible outliers caused by (i) contract rolls or (ii) policy shocks during the sample period that were not expected by market participants. We do so by adding a vector of dummy variables $\boldsymbol{D} = [Trade, Roll]$. We set $Trade$ equal to one on May 13th, 2020 (when China suspends tariffs on U.S. soybean imports) and zero otherwise. We set $Roll$ equal to one on the day before we roll the nearby futures from the prompt to the first-deferred (3 business day before the expiration month) and zero otherwise.[21]

Leads and lags for the first-differenced log ratios for volume ($\Delta lnRatio\_Vol$) and volatility ($\Delta lnRatio\_RV$) are included to correct for the simultaneity bias between the liquidity variable and

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[20] This last advantage is a major reason why we use DOLS rather than vector models such as the Vector Error Correction (VEC) and cointegrated Vector Autoregressive (VAR) models. Another widely used single-equation method for estimating cointegrating vectors is the Autoregressive Distributed Lag (ARDL) model. However, it does not perform well when multiple cointegrating relationships exist among the variables of interest (Pesaran, Shin, and Smith 2001). Using Johansen cointegration tests, we find multiple cointegrating relationships—which is consistent with the idea that volume, volatility, and liquidity are simultaneous determined.

[21] In robustness checks, we also control for possible USDA announcement-day effects and for GSCI commodity index rolling days. The coefficients for the dummies created to that effect are not statistically significant. The GSCI index rolling period from the March to the May soybean futures also overlaps with the beginning of the COVID-19 pandemic, which may partly explain the lack of significance of the GSCI variable.

market condition variables. We use the same truncation value K for both the leads and lags for first-differenced variables. In practice, K needs to be sufficiently large to include significant leads and lags but should not be too large compare to the sample size. We use a stepwise procedure to select K. Specifically, we begin with K=5, then reduce K by one if no significant leads and lags are found until we find at least one significant coefficient at the Kth lead or lag. The error term ϵ_t is assumed to be a stationary white noise.

4.3.c: Dynamic OLS Analysis: Results

Estimates of the parameters with heteroskedasticity- and autocorrelation-consistent standard errors for the cointegrating relationships are presented in Panel A *(resp. Panel B)* of Table 5 for the BAS *(resp. depth)* DOLS equations. Following the literature (e.g. Herwatz and Walle, 2014; Ireland, 2009), to promote clarity and to save space, we do not report parameter estimates for the leads and lags as the estimator treats short-run dynamics as nuisance parameters (Stock and Waltson, 1993).

Panel A in Table 5 shows the effect of the COVID-19 pandemic on the BAS in the outright and calendar spread markets during the day and night trading sessions. As expected, tighter quoted bid-ask spreads are associated with higher volume and lower realized volatility. From Table 4, we know that volume is mostly unchanged throughout the sample period, but that RV is statistically significantly higher from February 13 through April 9, 2020 (compared to the "pre-COVID" and "post-Fed" sub-periods). Panel A in Table 5 ties *part* of the increase in BAS during that eight-week sub-period to the contemporaneous RV increase. Our interest, however, is in whether there is an impact of the COVID-19 news on soybean BAS *over and above* what can be attributed to the increase in volatility. The fact that the COVID-19 dummy variable's coefficient is statistically significantly positive for outrights in the day session, indicates that the answer is positive.

More specifically, since we use a log ratio that represents year-over-year (YoY) percent changes, this result suggests that the year-over-year change in the day outright session BAS during the early stages of the pandemic (precisely, after cases skyrocket in China till the third intervention of the U.S. Federal Reserve in financial markets) is statistically significant and 1.5% higher (at the mean) compared to 2019. As noted in the previous paragraph, our model already controls for changes in trading volume and volatility: hence, this 1.5% estimate measures the liquidity cost increases over and above what can be attributed to changes in volume and volatility caused by the pandemic. The increase in hedging costs is thus both statistically and economically significant.

Panel B in Table 5 explores another aspect of liquidity provision during the pandemic: market depth. Again, the coefficients for the log ratios for volume and realized volatility have the expected signs. Over and above those effects, COVID-19 has a significant and negative impact on market depth in both outright and calendar spread markets. The results suggest that the day-session market depth decreased by 18.6% compared to the previous year in the outright market, while the night session quoted depth for outrights is not significantly affected by the pandemic (in both cases, these figures are the changes in excess of the increases that can be attributed to volume and volatility changes).

In the calendar spread market, strikingly more severe declines in quoted depth can be tied specifically to the novelty of the COVID-19 shock: spread depth at the top of the book evaporates (with period-average drops of 105.0% and 128.4% for the day and night sessions, respectively (the decreases exceed 100 percent because we control for changes in volume and volatility). The results expand on the findings in Figure 6 that, after the number of reported cases in China peaked on Feb

13, 2020, the depth in the outright market dropped by half, whereas the depth in the calendar spread market dropped by a whopping 90% and did not recover through the end of our sample period.

Diagnostic test results are presented in the lower panel of each table. Jarque-Bera test results suggest that residuals are normally distributed in all cases. Parameter stability tests based on the cumulative sum of recursive residuals fail to reject the null hypothesis of parameter stability at the 5% significance level in all cases.[22] We apply KPSS tests to residuals from the equations in order to examine the presence of cointegration relationships, and the test statistics suggest level variables are cointegrated in all cases.

4.3.d: Robustness

Our analysis thus far relies on events and liquidity provision in two years—2020 and 2019. While our methodology is designed to control for seasonality and other possible confounding factors, one might still worry that some of the liquidity differences between 2020 and 2019 could result from factors other than COVID-19. In this sub-Section, we use information from prior years in order to dispel this notion.

The first question to ask is what years should be used for this robustness check. Our interest is in how liquidity providers respond to market volatility in general and to the 2020 COVID-19 shock in particular. Therefore, it is critical that we choose additional years when futures liquidity changes cannot possibly be optical illusions resulting from shifts of market activity to other trading venues. In 2019 and 2020, this concern does not apply because all of the futures trading takes place on Globex (the exchange's electronic platform)—so the liquidity patterns we capture are "for real." Prior to July 2015, however, electronic trading took place side by side with pit trading. In such an environment, worries of "phantom" liquidity losses arise because, when electronic and floor venues co-exist, market activity migrates to the in-person venue during high-volatility periods (Goldstein and Kavajecz 2004). For this reason, our robustness analyses consider only data from 2016 to 2018, as in those years all soybean futures trading is electronic (as it is in 2019 and 2020) and migrations of trading and liquidity provision from Globex to the pits are therefore impossible.

The second question is about methodology. As noted in Section 2, in July 2018, the CME Group revised its rules regarding maximum order size and order execution for soybean calendar spreads. Although the new rules did not (and, to this day, do not) apply to outrights, they impact the latter indirectly insofar as liquidity flows between the spread and outright compartments of the futures market.[23] Thus, given the rule change, direct comparisons of liquidity changes amid stress before and after the summer of 2018 may be invalid not only for calendar spreads but also for outright

[22] The only exception, when we use recursive residuals, is for the night-session depth equation in the calendar spread market (column 4 in Panel B of Table 5). For that equation, reassuringly, a parameter stability test based on the cumulative sum of *non*-recursive residuals (which is less sensitive to the sample size) shows that the null hypothesis of parameter stability cannot be rejected at the 5% significance level. Furthermore, by checking the diagnostic plot, we find that the cumulative sum of recursive residuals exceeds the 5% significance confidence interval for a brief period, which suggest that parameters are stable for most of the sample period.

[23] Intuitively, a calendar spread combines a long position in a futures of a given maturity and a short position in a futures contract similar in all respects save the maturity date. Thus, anyone interested in trading a calendar spread can do so directly by entering an order in the calendar spread book or by entering separate long and short orders in the outright book. As a result, liquidity can flow from the outright book to the spread book, and *vice-versa*.

futures. For this reason, we devise an alternative approach that is similar in spirit to that adopted by Ruan *et al*. (2021) in their study of COVID-19's impact on vegetable prices in China.

We pick the two years in 2016-2018 that exhibit very high (2016, especially from April to June) and very low (2017) price volatility in the first six months of the year, and we apply our model by (i) using 2016 as a 2020-equivalent and 2017 as a 2019-equivalent and (ii) creating a placebo COVID-19 dummy variable in the same time interval in 2016 as in 2020. We find that the placebo variable is not statistically significant and does not explain variations in market liquidity in 2016 relative to 2017—see Appendix 2 for details. This result strengthens our conclusion that the significance of the COVID-19 variable in our main analysis captures the effect of the pandemic.

4.3.e: Discussion

Qualitatively, our results suggest that soybean futures liquidity provision decreased substantially during a stressful period of the global pandemic, particularly in the calendar spread market—where quoted depth almost evaporated. A natural question is whether this depth destruction matters for commercial hedgers, particularly in the case of the calendar spreads that are typically used by commercial merchandisers for hedging basis risk. Figures 8 and 9 suggest that the answer is "yes." These figures display the contribution of trades of different sizes (grouped in several size buckets) to the daily trading volume in the soybean futures outright (Panel A) and calendar spread (Panel B) markets in 2019 (Figure 8) and 2020 (Figure 9). A comparison of the corresponding plots shows that very large orders, which used to make up a sizeable share of the total calendar spread trading volume until February 13, 2020, almost disappear thereafter.

In sum, our results establish that the costs of the liquidity crisis are multiple: the onset of the COVID-19 pandemic reduced the ease with which large transactions could be carried out, and it raised transaction costs for smaller market orders (as proxied by the quoted BAS).

5. Conclusions and Future work

Our paper uses intraday trade-and-quote data to analyze the real-time impact of COVID-19 news in agricultural futures markets. We document that COVID-19 hurt soybean futures market quality significantly, a full two weeks before other U.S. financial or agricultural markets started to reflect the severity of the pandemic. We show that the soybean liquidity pullback cannot be explained solely by variables such as changes in trading volume or increases in realized price volatility: the COVID crisis was truly novel in the extent to which it impacted market liquidity.

For agricultural economists, our results provide evidence that the novelty of the COVID-19 crisis caused large commercial soybean futures traders major difficulties in placing very large trades and raised the costs of executing even small trades. As such, the COVID-19 crisis increased the cost of hedging substantially for those traders—especially for grain elevators and commodity merchandisers, since calendar spread liquidity suffered the most damage. For financial economists, our empirical analysis establishes that the COVID crisis demolished soybean-market liquidity in a way that foretold financial-market events two weeks later. As such, it indicates the importance of commodity-market signals. Our results show that the onset of the COVID-19 crisis was a one-of-a-kind shock to the soybean market, providing an early indication of the extent and magnitude that the shock would have on the wider U.S. economy.

As the pandemic continues, our results from the early stages of COVID-19 can help market participants to better understand the further potential impact of the virus on the liquidity provision and risk management functions of U.S. agricultural commodity markets. More broadly, our study helps to anticipate what would happen to market quality if markets were to face a fresh kind of disaster—one that causes unprecedented uncertainties with regards to demand and supply.

Our paper also opens several venues for further research. One relates to the physical-market developments associated with the soybean futures liquidity collapse. Schnitkey *et al*. (2020) document a sharp drop in U.S. farm returns in the spring of 2020. Yet, Mallory (2021) finds that U.S. and Brazilian grains and oilseed export quantities were not impacted by COVID-19 in the medium term. One possible explanation for this apparent discrepancy is that major logistical issues related to transporting soybeans to (or within) China took place, slowing down the movement of bulk commodities and forcing oilseed merchandisers to keep on their hedges for longer than usual. It would be interesting to combine data on international soybean shipping with regulatory data on trader-level positions in soybean futures market in order to test this hypothesis, and to investigate whether the soybean calendar-spread liquidity collapse was signaling such a breakdown.

Another interesting venue involves price discovery. U.S. futures market have long been known as ground zero for world food price discovery, with the day session contributing the most to price discovery (Janzen and Adjemian, 2017). We find that, from mid-February till early April 2020, realized price volatility soars in both the day and night sessions but the night-session increase is much larger. Why? Is that night-and-day difference due to an increase in the importance of news from overseas in the early stages of the COVID-19 pandemic? Or, does the night-session RV jump reflect a greater price impact (during that eight-week period) of overnight rebalancing trades by day-session liquidity providers who often use the night session to rebalance their inventory?

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Table 1. COVID-19 Crisis Timeline, 2020

Date	Event
January 23	Wuhan lock down.
February 13	China announces that daily cases of COVID 19 are up 10-fold
February 27	VIX spikes to almost 40, from less than 27.5 the day before
March 3	U.S. Federal Reserve ("Fed") cuts target range for the federal funds rate by 50bps *(largest single cut since 2008)*
March 17	Fed intervention: first round
March 23	Fed intervention: second round
April 9	Fed intervention: third round

Note: This table lists the dates of seven major events that affected U.S. agricultural and financial markets during the COVID-19 crisis.

Table 2. Summary Statistics

Panel A: Outright Soybean Futures Market Quality Measures

(Top 5 contracts, volume-weighted, first halves of 2019 and 2020)

2019	*Day session*				*Night session*			
Variable *(unit)*	Mean	Std.dev.	Min	Max	Mean	Std.dev.	Min	Max
Top depth *(number of contract)*	103	32	45	212	43	10	24	83
Bid-ask spread *(cents per bushel)*	0.2795	0.0063	0.2672	0.2945	0.3055	0.0115	0.2761	0.3402
Realized volatility *(cents squared)*	48.08	40.38	9.93	2.95	27.57	25.46	5.43	177.36
2020	*Day session*				*Night session*			
Variable (unit)	Mean	Std.dev.	Min	Max	Mean	Std.dev.	Min	Max
Top depth *(number of contract)*	109	39	39	210	48	17	20	111
Bid-ask spread (cents *per bushel*)	0.2775	0.0055	0.2671	0.2931	0.3068	0.0155	0.2852	0.3568
Realized volatility *(cents squared)*	41.99	20.84	11.23	127.02	35.26	25.49	8.90	159.86

<u>*Notes*</u>: This table presents the summary statistics for the daily volume-weighted measures of (i) top-of-the-book depth, (ii) quoted bid-ask spread (BAS), and (iii) realized volatility in the soybean outright futures market. Our measures are volume-weighted across the five most active CBOT soybean futures. For each day in our sample period, Tables A1 (2019) and A2 (2020) in the Appendix list the set of the five most-traded contracts: we keep this set constant for two months at a time—we redefine the “nearby” contract at the end of February, and again at the end of April. We compute the daily weights separately for the day and night sessions. (i) The top depth (expressed as the number of contracts bid or offered at the best quote) is the daily volume-weighted average of the best bid depth and best ask depths for the five most-traded contracts. We first compute the top depth for each of the top-five contracts, using the simple daily session averages of the sums of the bid and ask depths posted at the best bid and ask quotes, then we compute daily volume-weighted averages of the contract-level figures across the top five contracts, and finally we compute—and report in the above Table—the sample summary statistics. (ii) We proceed similarly for the bid-ask spread, which is measured in cents per bushel. (iii) For realized volatility, we proceed similarly using the sum of squares of five-minute non-overlapping returns. The “Day” and “Night” sessions are based on the CBOT day trading hours (from 8:30 a.m. to 1:20 p.m., Monday to Friday) and night trading hours (from 7:00 p.m. to 7:45 a.m., Sunday to Friday). Sample period: second Monday in January through the last Wednesday in June, in 2019 and in 2020. **Source**: CME Group and authors’ computations.

Panel B: Soybean Calendar-Spread Market Quality Measures

(Top 5 contracts, volume-weighted, first halves of 2019 and 2020)

2019	*Day session*				*Night session*			
Variable *(unit)*	Mean	Std.dev.	Min	Max	Mean	Std.dev.	Min	Max
Top depth *(number of contract)*	90,913	86,201	3,095	359,298	32,648	31,549	947	191,642
Bid-ask spread *(cents per bushel)*	0.2531	0.0027	0.2500	0.2623	0.2561	0.0056	0.2500	0.2765
Realized volatility *(cents squared)*	1.34	0.42	0.59	2.95	1.05	0.56	0.26	2.38
2020	*Day session*				*Night session*			
Variable (unit)	Mean	Std.dev.	Min	Max	Mean	Std.dev.	Min	Max
Top depth *(number of contract)*	7,914	13,581	170	58,688	2,519	4,250	51	21,393
Bid-ask spread (cents *per bushel*)	0.2616	0.0097	0.2510	0.2958	0.2772	0.0223	0.2511	0.3637
Realized volatility *(cents squared)*	3.11	2.28	0.82	16.80	2.25	1.88	0.55	11.77

Notes: This table presents the summary statistics for the daily volume-weighted measures of (i) top-of-the-book depth, (ii) quoted bid-ask spread (BAS), and (iii) realized volatility in the soybean calendar spread market. Our measures are volume-weighted across the five most active CBOT soybean futures. For each day in our sample period, Tables A1 (2019) and A2 (2020) in the Appendix list the set of the five most-traded soybean-futures calendar spreads: we keep this set constant for two months at a time—we redefine the "nearby" futures at the end of February, and again at the end of April. We compute the daily weights separately for the day and night sessions. (i) The top depth (expressed as the number of contracts bid or offered at the best quote) is the daily volume-weighted sum of the best bid depth and best ask depths for the five most-traded contracts. We first compute the top depth for each of the top-five calendar spreads, using the simple daily session averages of the sums of the bid and ask depths posted at the best bid and ask quotes, then we compute daily volume-weighted averages of the contract-level figures across the top five contracts, and finally we compute—and report in the above Table—the sample summary statistics. (ii) We proceed similarly for the bid-ask spread, which is measured in cents per bushel. (iii) For realized volatility, we proceed similarly using the sum of squares of five-minute non-overlapping returns. The "Day" and "Night" sessions are based on the CBOT day trading hours (from 8:30 a.m. to 1:20 p.m., Monday to Friday) and night trading hours (from 7:00 p.m. to 7:45 a.m., Sunday to Friday). Sample period: second Monday in January through the last Wednesday in June, in 2019 and in 2020. **Source**: CME Group and authors' computations.

Table 3. Stationarity Test Results *(2020 vs. 2019 ratios)*

	Outright Futures				Calendar Spread			
	Day Session		Night Session		Day Session		Night Session	
	ADF	KPSS	ADF	KPSS	ADF	KPSS	ADF	KPSS
$lnRatio\_Vol$	-3.351**	0.763***	-2.736	0.884***	-3.456**	0.778***	-6.444	0.025***
$lnRatio\_RV$	-2.425	0.794***	-1.696	0.802***	-2.056	0.425	-8.017	0.052**
$lnRatio\_Depth$	0.534	0.647**	-0.814	0.647**	-2.365	0.482**	-8.803	0.113**
$\mathrm{ln}Ratio\_BAS$	0.591	0.516**	-1.297	0.482**	-1.849	0.444	-8.762	0.078**
$\Delta lnRatio\_Vol$	-8.080***	0.037	-9.764***	0.039	0.153***	1.021	-10.586***	0.085
$\Delta lnRatio\_RV$	-11.623***	0.045	-8.902***	0.070	0.293***	0.027	-9.682***	0.053
$\Delta lnRatio\_Depth$	-11.300***	0.128	-7.723***	0.120	0.180***	0.046	-8.803***	0.064
$\Delta lnRatio\_BAS$	-10.686***	0.125	-4.395***	0.104	0.340***	0.021	-8.773***	0.056

Notes: This table displays the test statistics for the ADF and KPSS tests for the order of integration of the log ratio series (2020 figure vs. matching-day 2019 figure) and of their first differences, for volume (Vol), realized volatility (RV), top-of-the-book depth (Depth), and bid-ask spread (BAS). The RV, depth, and BAS measures are defined in Tables 1 (for outright futures) and 2 (for calendar spreads). The daily trading volume and the volume weights for the other three measures are computed for the top-five most-traded contracts in January-February, March-April, or May-June. The stationarity tests are specified with a constant. The null hypothesis for the ADF test is that the series is nonstationary. The KPSS test has the null hypothesis of level stationary. Lags for stationarity tests are selected based on the AIC. ** and *** indicate significance at the 5% and 1% level, respectively. Sample period: second Monday in January through last Wednesday in June, in 2019 and in 2020. **Source**: CME Group and authors' computations.

Table 4: Volume, Bid-Ask Spreads, Depth, and Realized Volatility

Before, During, and After **the Onset of the COVID-19 Crisis**

		Outright			Calendar Spread		
		Jan.13-Feb.12 ("Pre-COVID")	Feb.13-April 9 ("COVID")	Apr.10-Jun.26 ("Post-Fed")	Jan.13-Feb.12 ("Pre-COVID")	Feb.13-Apr.9 ("COVID")	Apr.10-Jun.26 ("Post-Fed")
lnRatio_Vol	Day Session	0.01	0.11	**-0.25†**	0.12	0.35	-0.16†
	Night Session	0.47	0.59	**-0.04†**	0.37	**0.87†**	**-0.22†**
lnRatio_Depth	Day Session	0.35	**-0.38†**	**0.23†**	-1.14	**-4.36†**	**-3.33†**
	Night Session	0.22	**-0.24†**	**0.28†**	-1.51	**-4.05†**	**-3.08†**
lnRatio_BAS	Day Session	-0.03	**0.02†**	**-0.02†**	0.00	**0.05†**	**0.03†**
	Night Session	-0.02	**0.04†**	**-0.01†**	0.00	**0.11†**	0.09
lnRatio_RV	Day Session	-0.02	**0.55†**	**-0.47†**	0.16	**1.07†**	**0.73†**
	Night Session	0.35	**1.12†**	**-0.25†**	0.42	**1.34†**	**0.38†**

Notes: This table shows the mean values of the natural logarithm of the ratio of 2020 (numerator) *vs*. 2019 (denominator) daily trading volume, top-of-book quoted depth, quoted bid-ask spreads (BAS), and realized volatility (RV) for each of the three sub-sample periods. Volume-weighted averages based on the five most-traded contracts are used to compute the ratios for depth, spreads, and RV—see Tables 1 and 2 for details regarding computations of those volume-weighted values for outright futures and calendar spreads, respectively. Log ratios are computed separately for the U.S. day and night trading sessions, in the outright and in the calendar spread futures markets. We match trading days in 2020 and 2019 to avoid day-of-week effects when computing the ratios. The symbol † indicates the value of the 2020/2019 ratio in a given sub-period is statistically significantly different from the ratio in the preceding sub-period (with the significance evaluated at the 5% confidence level based on bootstrap t-test with 1000 draws). In the outright market, quoted depth *(resp. bid-ask spreads)* drops dramatically *(resp. increase significantly)* during the COVID period (i.e., second interval, from Feb. 13 to April 9) and then rebounds *(resp. fall back)* to almost pre-COVID levels. In the calendar spread market, quoted depth drops dramatically and bid-ask spreads increase significantly after February 13, 2020—but neither reverts to pre-crisis levels despite the U.S. Federal Reserve's intervention. Sample period: second Monday in January through last Wednesday in June, in 2019 and in 2020. **Source**: CME Group and authors' computations.

Table 5. COVID-19 Impact on Soybean Market Liquidity—DOLS Estimates

Panel A: Impact of COVID-19 on Bid-Ask Spreads

	Outright		Calendar Spread	
	Day Session(k=5)	Night Session(k=5)	Day Session (k=2)	Night Session(k=5)
lnRatio_Vol$_t$	-0.088***	-0.153***	-0.004	-0.100***
	(0.015)	(0.028)	(0.013)	(0.018)
lnRatio_RV$_t$	0.055***	0.123***	0.047***	0.124***
	(0.004)	(0.012)	(0.009)	(0.013)
COVID$_t$	0.015***	-0.021	0.011	0.023
	(0.006)	(0.011)	(0.007)	(0.016)
Trade	-0.030***	-0.051***	0.096***	0.053**
	(0.011)	(0.018)	(0.008)	(0.026)
Roll	0.010	0.014	0.038**	0.112**
	(0.014)	(0.026)	(0.013)	(0.055)
N	112	112	112	112
R^2	0.832	0.773	0.613	0.583
Normality (Jarque-Bera test)	0.148	3.550	1.338	3.449
Residual Stationarity (KPSS)	0.188	0.064	0.063	0.373
Parameter Stability (CUMSUM)	0.604	0.895	1.016**	0.492

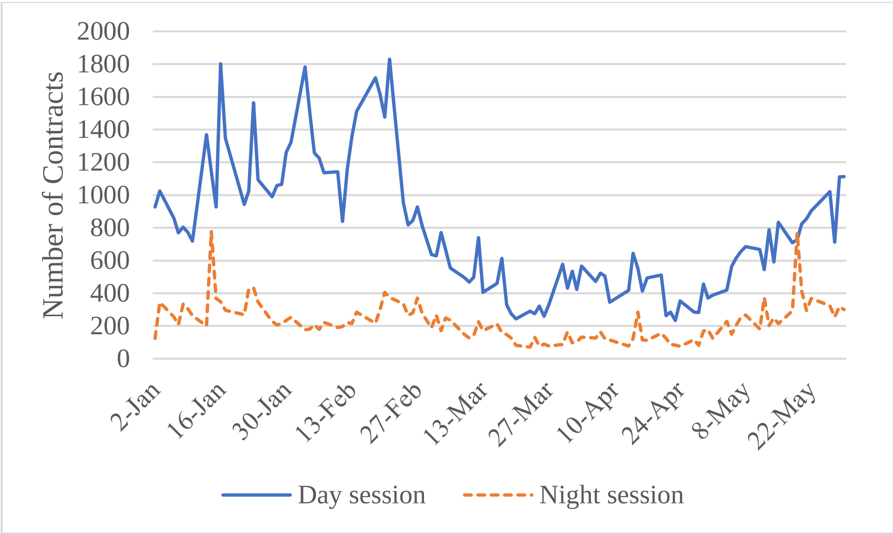
Notes: This table presents Dynamic Ordinary Least-Squares (DOLS) estimates of the impact of the COVID-19 crisis on quoted bid-ask spreads in the outright soybean futures and calendar spread markets during the day and night trading sessions. The right-hand side variables are: *lnVol_Ratio* is the natural logarithm ("log") of the trading volume ratio in 2020 (numerator) *vs*. 2019 (denominator); *lnRV_Ratio*$_t$ is the log of the realized volatility ratio in 2020 *vs*. 2019; trading days are matched each year to avoid day-of-week effects when computing the ratios. Daily values of BAS and RV are computed using volume-weighted averages across the top five most active contracts, as explained in Table 4. *COVID* is a dummy variable that captures the heart of the soybean crisis in the soybean futures market: it equals one between Feb 13th, 2020 and April 09th, 2020 and zero otherwise. *Trade* is a dummy variable that equals one on May 13th, 2020 (the day when China suspended tariffs on U.S. soybean imports) and zero otherwise. *Roll* is a dummy variable that equals one on the day before the prompt contract's first position day and zero otherwise. Heteroskedastic and autocorrelation robust standard errors are presented in parentheses. ** and *** denotes significance at the 5% and 1% levels, respectively. Sample period: January 13 to June 24, 2020 and matching days in 2019.

Panel B: Impact of COVID-19 on Market Depth

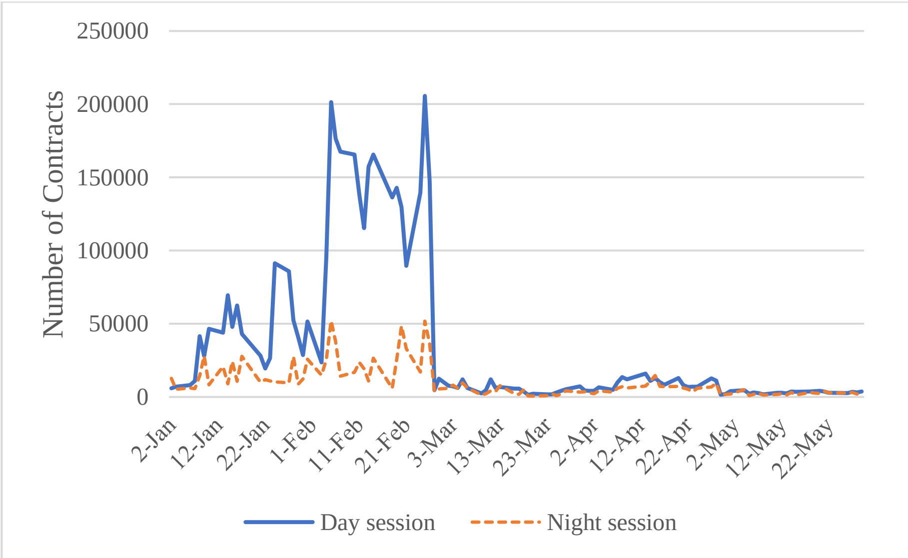
	Outright		Calendar Spread	
	Day Session(k=4)	Night Session(k=4)	Day Session (k=5)	Night Session(k=5)
lnRatio_Vol$_t$	1.382***	0.674***	1.875***	0.880
	(0.213)	(0.160)	(0.518)	(0.536)
lnRatio_RV$_t$	-0.959***	-0.757***	-2.743***	-0.977***
	(0.051)	(0.077)	(0.413)	(0.344)
COVID$_t$	-0.186**	0.039	-1.050**	-1.284**
	(0.088)	(0.078)	(0.437)	(0.588)
Trade	0.144	-0.229***	-0.801	-1.908***
	(0.120)	(0.086)	(0.422)	(0.543)
Roll	-0.012	0.169	-0.433	-1.121
	(0.119)	(0.118)	(0.716)	(0.863)
N	112	112	112	112
R^2	0.863	0.847	0.697	0.335
Normality (Jarque-Bera test)	1.102	2.746	0.901	5.658
Residual Stationarity (KPSS)	0.365	0.069	0.115	0.425
Parameter Stability (CUMSUM)	0.356	0.366	0.821	0.954**

Notes: This table presents Dynamic Ordinary Least-Squares (DOLS) estimates of the impact of the COVID-19 crisis on the top-of-book quoted depth in the outright soybean futures and calendar spread markets during the day and night trading sessions. The right-hand side variables are: *lnVol_Ratio* is the natural logarithm ("log") of the trading volume ratio in 2020 (numerator) *vs*. 2019 (denominator); *lnRV_Ratio*$_t$ is the log of the realized volatility ratio in 2020 *vs*. 2019; trading days are matched each year to avoid day-of-week effects when computing the ratios. Daily estimates of top depth and RV are based on volume-weighted *averages* using the top five most active contracts, as explained in Tables 1-2. *COVID* is a dummy variable that captures the first phase of the liquidity crisis in the soybean futures market: it equals one between Feb 13th, 2020 and April 09th, 2020 and zero otherwise. *Trade* is a dummy variable that equals one on May 13th, 2020 (the day when China suspended tariffs on U.S. soybean imports) and zero otherwise. *Roll* is a dummy variable that equals one on the day before the prompt contract's first position day and zero otherwise. Heteroskedastic and autocorrelation robust standard errors are presented in parentheses. ** and *** denotes significance at the 5% and 1% levels, respectively. Sample period: January 13 to June 24, 2020 and matching days in 2019.

Figure 1—Panel A: Nearby Corn Futures Top-of-the-Book Depth, 2020



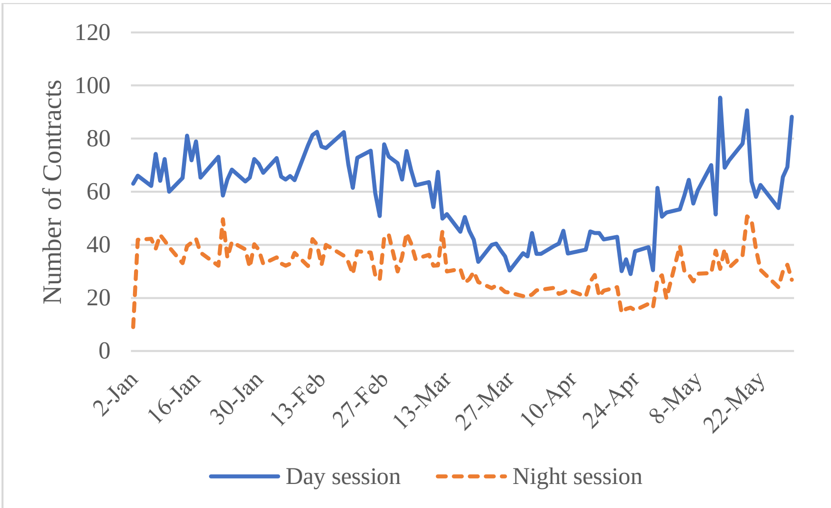
(a) Outright market



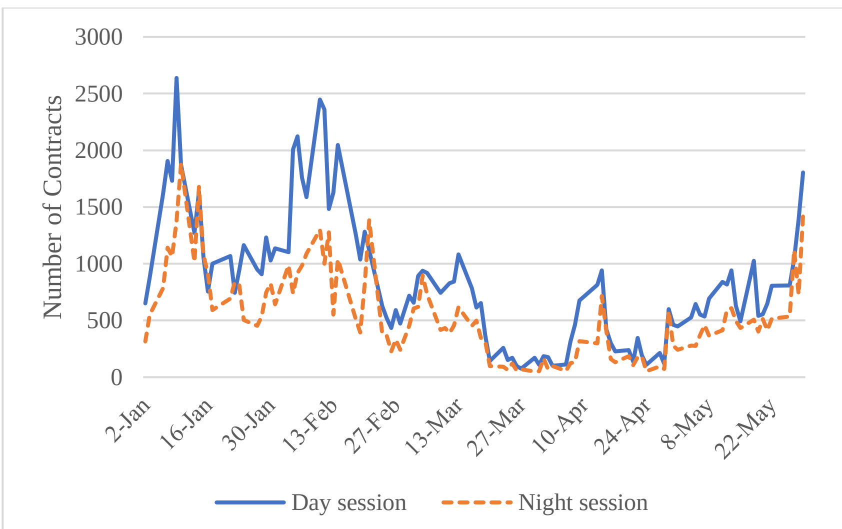
(b) Calendar spread market

Notes: This figure displays the top-of-the-book depth for the nearby contract in both outright and calendar spread corn futures markets from January 2 to May 29, 2020. We roll over the "nearby" contract to the next maturity on the "first position" day (i.e., two business days before the start of the delivery month). We measure the top depth using the simple daily session averages of the sums of the bid and ask depths posted at the best bid and ask quotes. The solid blue line shows depth during the day session, while the dotted orange line shows the night trading session. CBOT has the day trading hours from 8:30 a.m. to 1:20 p.m. Monday to Friday and night trading session from 7:00 p.m. – 7:45 a.m. Sunday to Friday. Source: CME Group and authors' computations.

Figure 1—Panel B: Nearby Wheat Futures Top-of-the-Book Depth, 2020



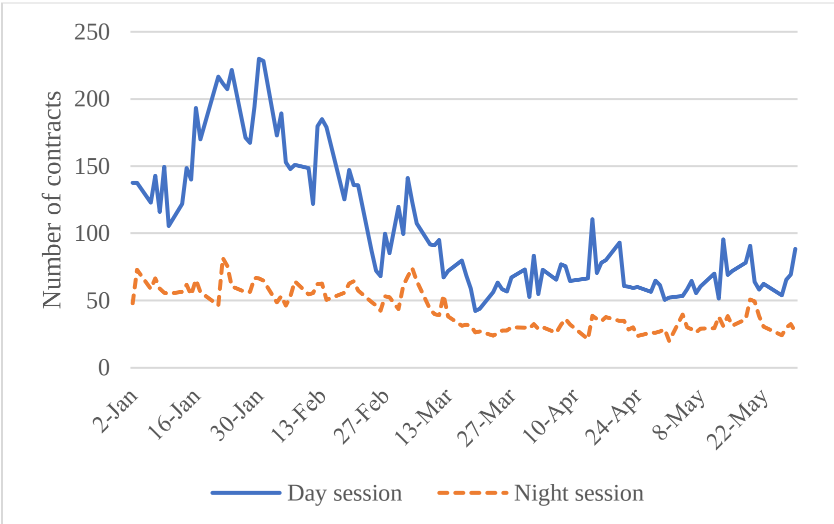
(a) Outright market



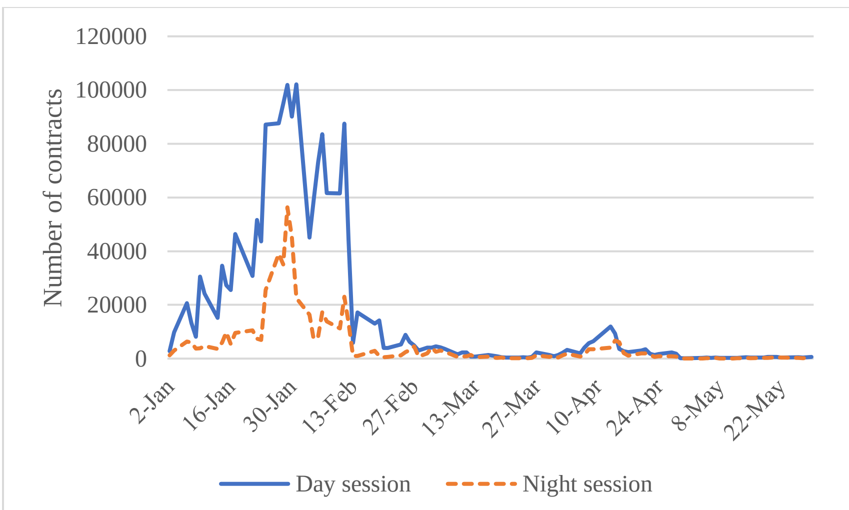
(b) Calendar spread market

Notes: This figure displays the top-of-the-book depth for the nearby contract in both outright and calendar spread soft red winter (SRW) wheat futures markets from January 2 to May 29, 2020. We roll over the "nearby" contract to the next maturity on the "first position" day (i.e., two business days before the start of the delivery month). We measure the top depth using the simple daily session averages of the sums of the bid and ask depths posted at the best bid and ask quotes. The solid blue line shows depth during the day session, while the dotted orange line shows the night trading session. CBOT has the day trading hours from 8:30 a.m. to 1:20 p.m. Monday to Friday and night trading session from 7:00 p.m. – 7:45 a.m. Sunday to Friday. Source: CME Group and authors' computations.

Figure 1—Panel C: Nearby Soybean Futures Top-of-the-Book Depth, 2020



(a) Outright market

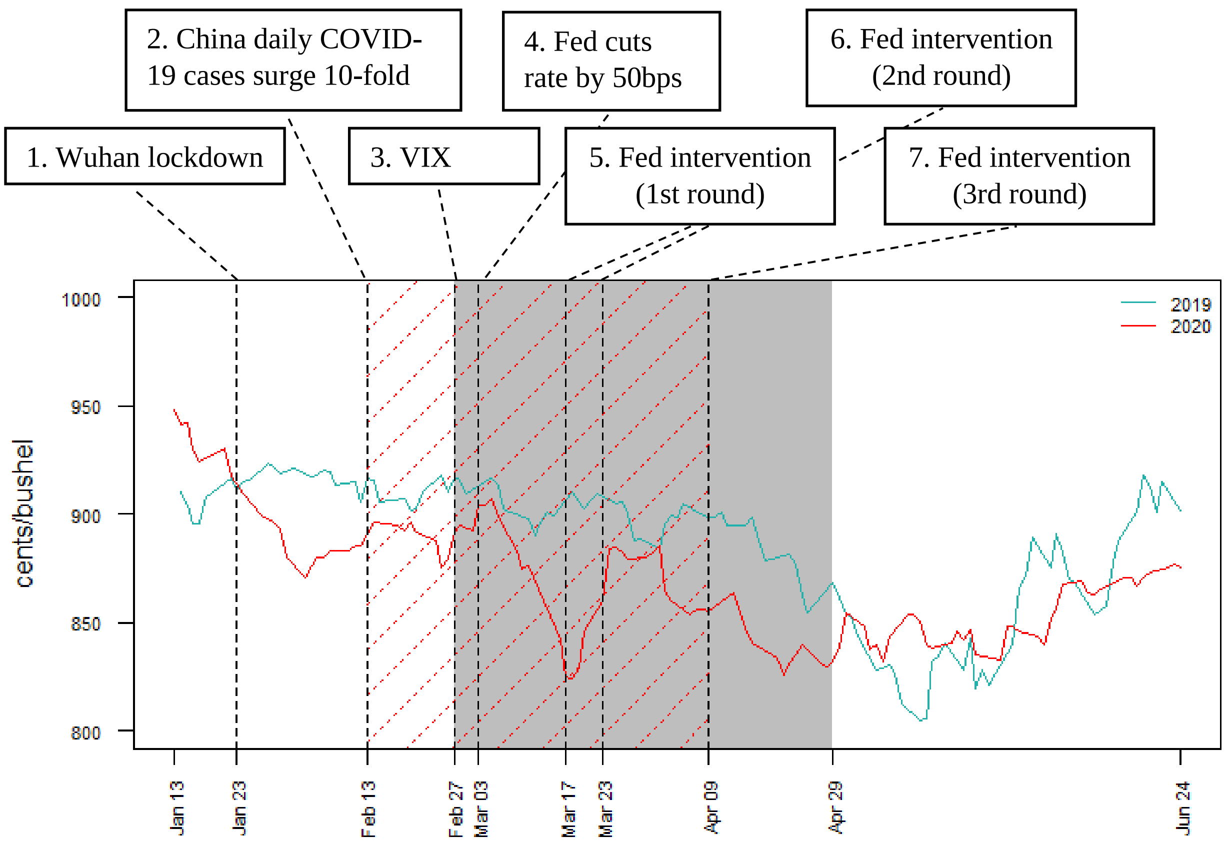


(b) Calendar spread market

Notes: This figure displays the top-of-the-book depth for the nearby contract in both outright and calendar spread soybean futures markets from January 2 to May 29, 2020. We roll over the "nearby" contract to the next maturity on the "first position" day (i.e., two business days before the start of the delivery month). We measure the top depth using the simple daily session averages of the sums of the bid and ask depths posted at the best bid and ask quotes. The solid blue line shows depth during the day session, while the dotted orange line shows the night trading session. CBOT has the day trading hours from 8:30 a.m. to 1:20 p.m. Monday to Friday and night trading session from 7:00 p.m. – 7:45 a.m. Sunday to Friday. Source: CME Group and authors' computations.

Figure 2—Panel A:

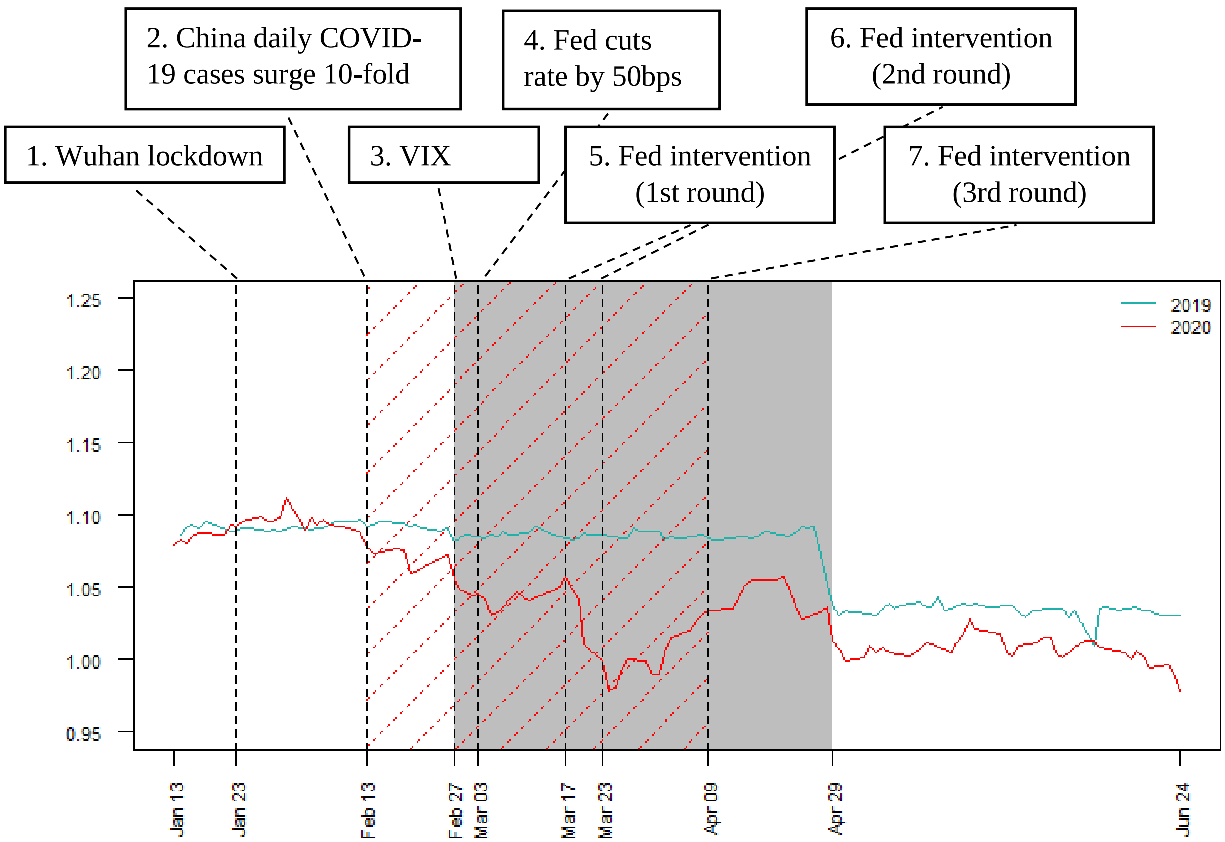
Soybean Futures Price in the Early COVID-19 Pandemic Period



Notes: This figure plots the daily U.S. soybean nearby-futures settlement price (in cents per bushel) during the first half of 2020 (plotted in red) and the same period in 2019 (plotted in green). The dates of major COVID-19 developments in 2020 are indicated by vertical back dash lines, with a small explanation in boxes above the plot. The first phase of the COVID-19 liquidity crisis in the soybean market (Feb 13th to Apr 9th, 2020) is indicated by the slanted red dotted lines. To identify contract rolls, we separate by the gray shaded area three periods: January and February, when the March soybean futures is the prompt contract; March and April, when the prompt contract is May; and May and June, when the prompt contract is the July futures. Source of futures settlement-price data: CME Group.

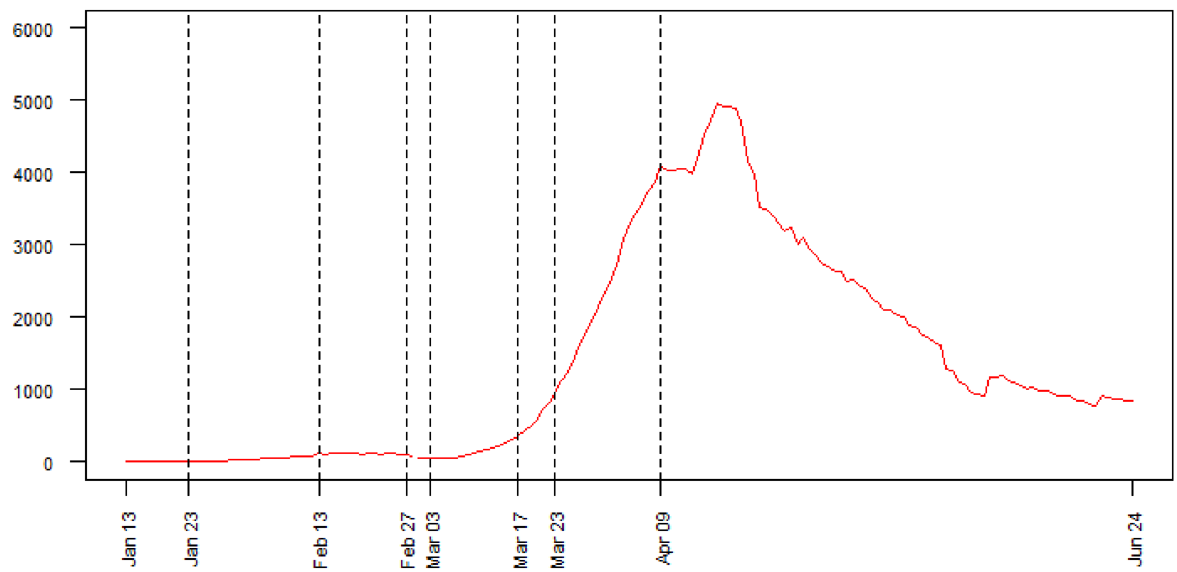
Figure 2—Panel B:

Soybean Cost-of-Carry Factor in the Early COVID-19 Pandemic Period



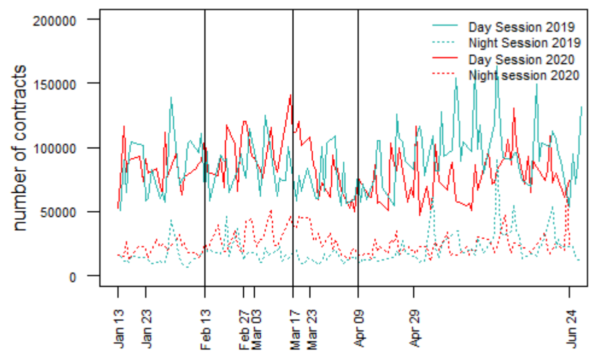
Notes: This figure plots the daily value of the slope of the soybean futures term structure during the first half of 2020 (plotted in red) and the same period in 2019 (plotted in green). Daily values of the cost-of-carry (in cents per bushel) are calculated using simple averages of the prices of calendar spreads for the three most-actively traded contract pairs along the futures term curve: nearby *vs*. first deferred, nearby *vs*. second deferred, and first-deferred *vs*. second-deferred futures contracts. The slope plotted above is the annualized value of the cost-of-carry factor; for example, a value of 1.06 means that the 2-month cost of carry is one percent and the annual equivalent is six percent. The dates of major COVID-19 developments in 2020 are indicated by vertical back dash lines, with a small explanation in boxes above the plot. The first phase of the COVID-19 liquidity crisis in the soybean market (Feb 13th to Apr 9th, 2020) is indicated by the slanted red dotted lines. To identify contract rolls, we separate by the gray shaded area three periods: January and February, when the March soybean futures is the prompt contract; March and April, when the prompt contract is May; and May and June, when the prompt contract is the July futures. Source: CME Group and authors' computations.

Figure 3. Daily New COVID-19 Deaths, January 13th to June 24th, 2020

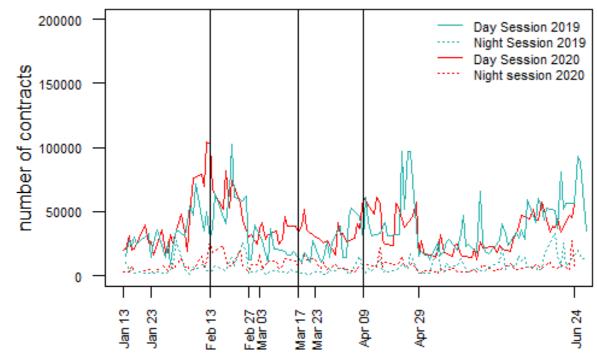


Notes: This figure plots a 7-day moving average of the daily total of new COVID-19 deaths in China, the United States, and the five largest countries in Western Europe (Spain, Italy, Germany, France, and the United Kingdom) during the early period of the COVID-19 pandemic (January 13 to June 24, 2020). Event days related to COVID-19 are indicated by vertical back dash lines—see Figure 1. **Source:** Center for Disease Control of the European Union.

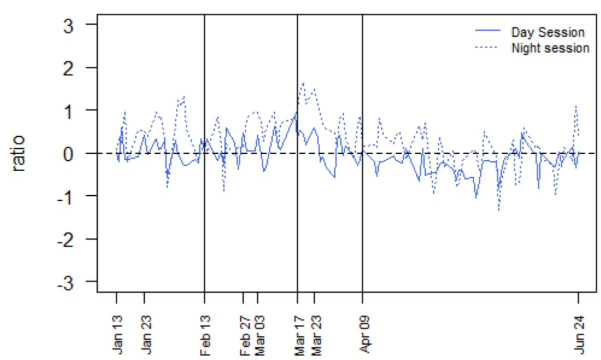
Figure 4: Trading Volume and 2020 *vs*. 2019 Volume Ratio



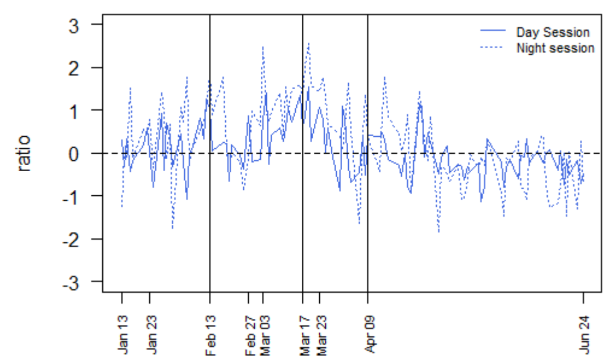
(A) Volume in outright market



(B) Volume in calendar spread market



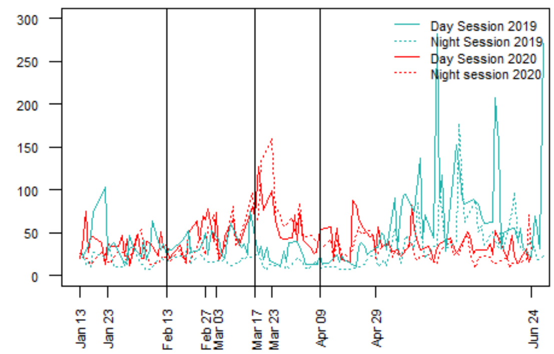
(C) Volume ratio in outright market



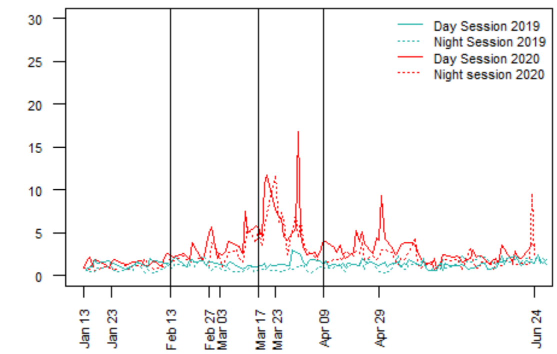
(D) Volume ratio in calendar spread market

Notes: Panels A and B of this figure show the total trading volume in 2020 (plotted in red) and 2019 (plotted in green) for the five most-traded contracts in the outright (Panel A) and calendar spread (Panel B) compartments of the soybean futures markets. Panels C and D show the log ratios of the red and green lines (outright futures in Panel C, calendar spreads in Panel D). In all four panels, the solid lines represent values in the day session while the dotted lines stand for the night trading session. CBOT has day trading hours from 8:30 a.m. to 1:20 p.m. Monday to Friday and night trading hours from 7:00 p.m. – 7:45 a.m. Sunday to Friday. In all panels, the 2020 and 2019 trading days are matched to avoid day-of-week effects when computing the ratios. Sample period: second Monday in January through last Wednesday in June, in 2019 and in 2020. Source: CME Group and authors' computations.

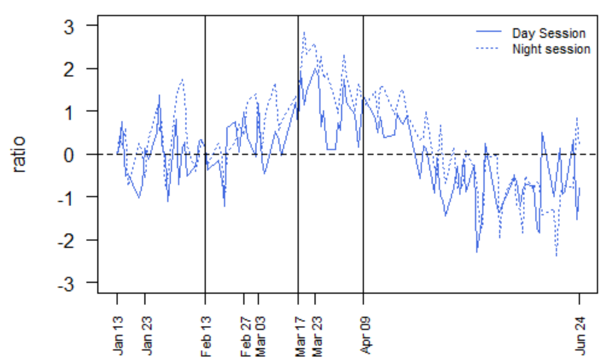
Figure 5: Realized Volatility (RV) and 2020 *vs*. 2019 RV Ratio



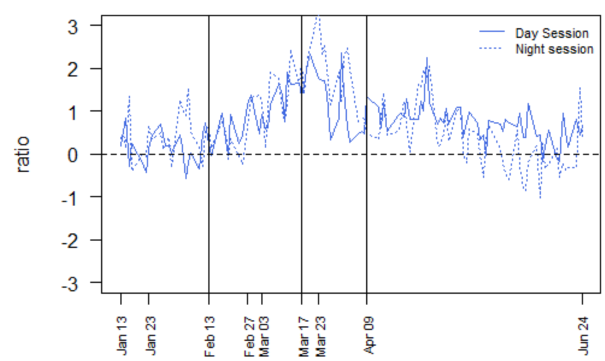
(A) Realized volatility in outright market



(B) Realized volatility in calendar spread market



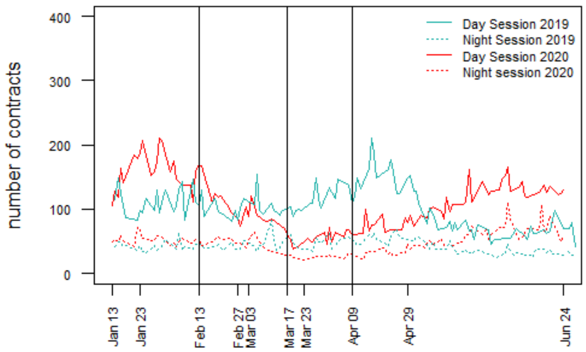
(C) Realized volatility ratio in outright market



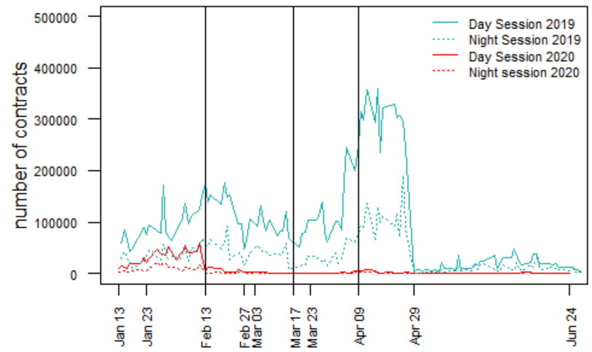
(D) Realized volatility ratio in calendar spread market

Notes: Panels a and b plot the daily values in 2020 (plotted in red) and in 2019 (plotted in green) of the realized soybean futures return volatility (RV). Daily values of the RV are computed using volume-weighted averages across the top five most active contracts, as explained in Table 4. RV plots are provided for the outright (Panel A) and calendar spread (Panel B) compartments of the soybean futures markets. Panels C and D show the log ratios of the corresponding red and green lines (outright futures in Panel C, calendar spreads in Panel D). In all four panels, the solid lines represent values in the day session while the dotted lines stand for the night trading session. CBOT has day trading hours from 8:30 a.m. to 1:20 p.m. Monday to Friday and night trading hours from 7:00 p.m. – 7:45 a.m. Sunday to Friday. In all panels, the 2020 and 2019 trading days are matched to avoid day-of-week effects when computing the ratios. Sample period: second Monday in January through last Wednesday in June, in 2019 and in 2020. Source: CME Group and authors' computations.

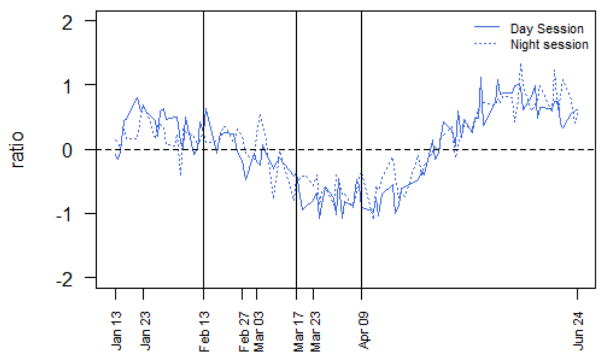
Figure 6: Top-of-the-Book Depth and 2020 *vs*. 2019 Depth Ratio



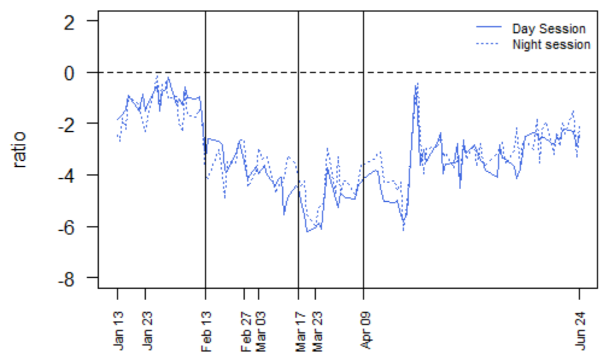
(A) Depth in outright market



(B) Depth in calendar spread market



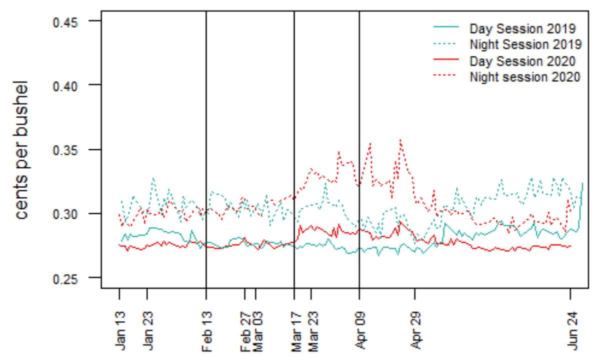
(C) Depth ratio in outright market



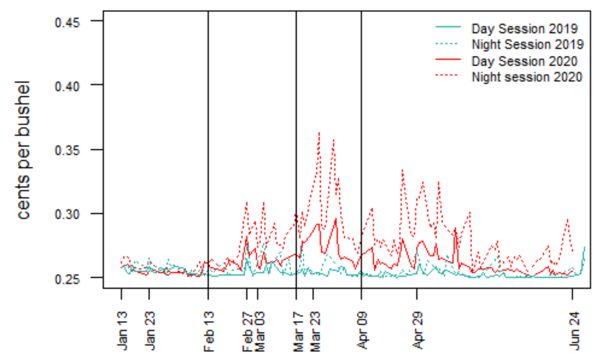
(D) Depth ratio in calendar spread market

Notes: Panels A and B of this figure plot the daily values in 2020 (in red) and in 2019 (in green) of the soybean futures top-of-the-book depth. The top depth is measured as the number of contracts at the best bid and ask quotes: note that top depth is two to three orders of magnitude greater in the spread market (Panel B) than in the outright market (Panel A). Daily top-of-the-book depth values are computed using volume-weighted averages across the top five most active contracts, as explained in Table 2A (outrights) and Table 2B (calendar spreads). Panels C and D show the log ratios of the corresponding red and green lines (outright futures in Panel C, calendar spreads in Panel D). In all four panels, the solid lines represent values in the day session while the dotted lines stand for the night trading session. CBOT has day trading hours from 8:30 a.m. to 1:20 p.m. Monday to Friday and night trading hours from 7:00 p.m. – 7:45 a.m. Sunday to Friday. In all panels, the 2020 and 2019 trading days are matched to avoid day-of-week effects when computing the ratios. Sample period: second Monday in January through last Wednesday in June, in 2019 and in 2020. Source: CME Group and authors' computations.

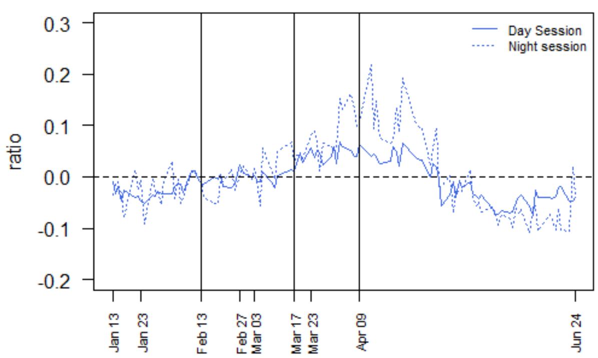
Figure 7: Bid-Ask Spread (BAS) and 2020 *vs*. 2019 BAS Ratio



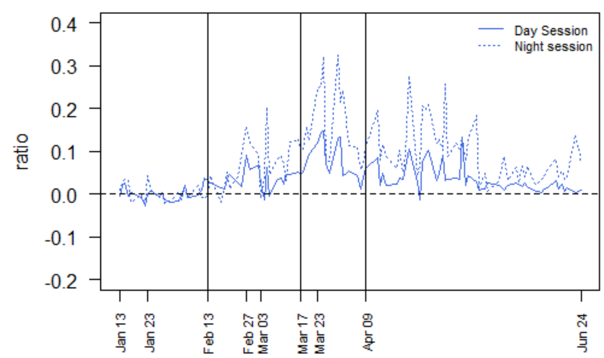
(A) BAS in outright market



(B) BAS in calendar spread market



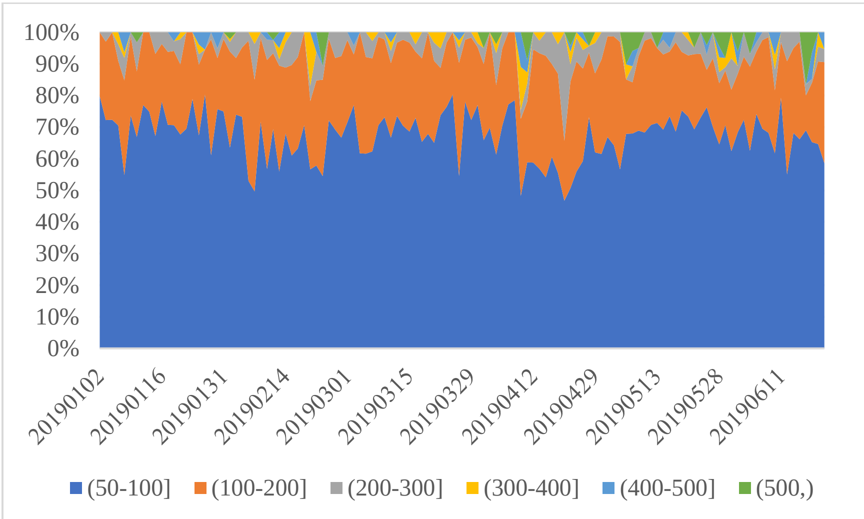
(C) BAS ratio in outright market



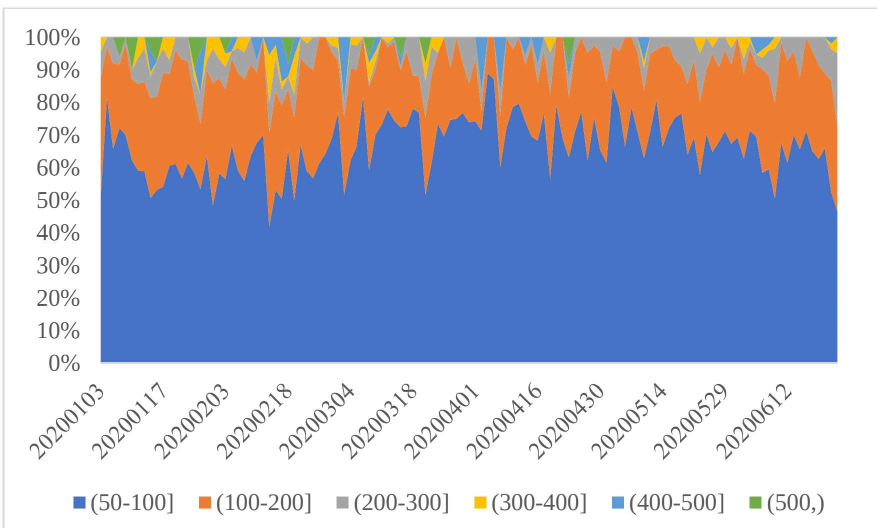
(D) BAS ratio in calendar spread market

Notes: Panels A and B plot the daily values in 2020 (in red) and in 2019 (in green) of the quoted bid-ask spread (BAS, in cents per bushel). Daily values of the BAS are computed using volume-weighted averages across the top five most active contracts, as explained in Table 4. BAS plots are provided for the outright (Panel A) and calendar spread (Panel B) compartments of the soybean futures markets. Panels C and D show the log ratios of the corresponding red and green lines (outright futures in Panel C, calendar spreads in Panel D). In all four panels, the solid lines represent values in the day session while the dotted lines stand for the night trading session. CBOT has day trading hours from 8:30 a.m. to 1:20 p.m. Monday to Friday and night trading hours from 7:00 p.m. – 7:45 a.m. Sunday to Friday. In all panels, the 2020 and 2019 trading days are matched to avoid day-of-week effects when computing the ratios. Sample period: second Monday in January through last Wednesday in June, in 2019 and in 2020. Source: CME Group and authors' computations.

Figure 8: Soybean Futures—Outright Volume Shares by Trade Size



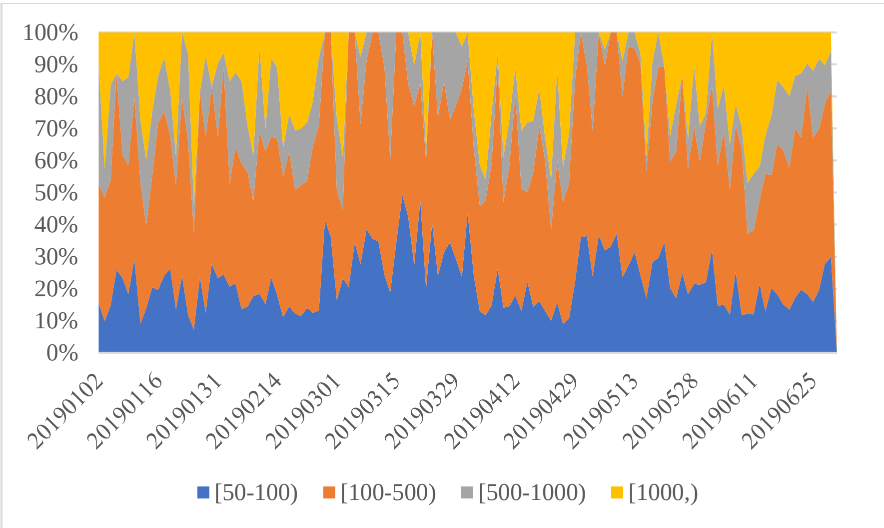
(a) First half of 2019



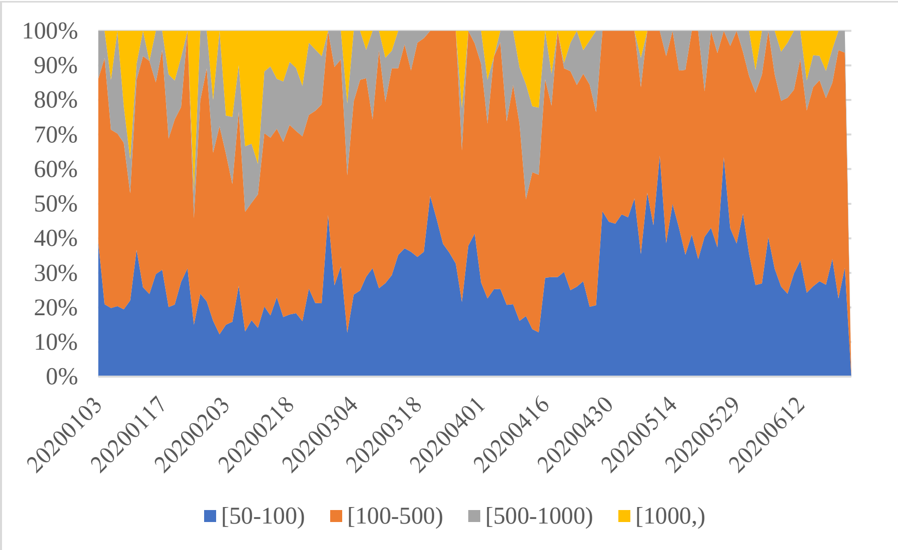
(b) First half of 2020

Notes: This figure plots the contribution by trades of different sizes (grouped in six buckets) to the daily soybean futures outright trading volume in 2019 (Panel A) and 2020 (Panel B). Sample period: January to June, in 2019 and in 2020.

Figure 9: Soybean Calendar Spread—Volume Shares by Trade Size



(a) First half of 2019



(b) First half of 2020

<u>Notes</u>: This figure plots the contribution of trades of different sizes (grouped in four buckets) to the daily soybean calendar-spread trading volume in 2019 (Panel A) and 2020 (Panel B). In both years, the maximum order size allowed is 10,000 contracts. Sample period: January to June, in 2019 and in 2020

Appendix 1:

Table A1: Volume Shares of the 5 Most-traded Contracts Soybean Contracts, H1-2019

	Jan-Feb		**Mar-Apr**		**May-Jun**	
	Contract	Share	Contract	Share	Contract	Share
Outright	ZSH9	0.6458	ZSK9	0.6139	ZSN9	0.6632
	ZSK9	0.2013	ZSN9	0.2633	ZSX9	0.2342
	ZSN9	0.0912	ZSX9	0.0906	ZSQ9	0.0539
	ZSX9	0.0563	ZSQ9	0.0209	ZSU9	0.0298
	ZSQ9	0.0054	ZSH0	0.0113	ZSF0	0.0119
	Jan-Feb		**Mar-Apr**		**May-Jun**	
	Contract	Share	Contract	Share	Contract	Share
Calendar spread	ZSH9-ZSK9	0.5337	ZSK9-ZSN9	0.6292	ZSN9-ZSX0	0.5157
	ZSH9-ZSN9	0.1894	ZSN9-ZSX9	0.1747	ZSN9-ZSQ9	0.2161
	ZSK9-ZSN9	0.1458	ZSK9-ZSX9	0.0621	ZSQ9-ZSX9	0.1085
	ZSN9-ZSX9	0.0885	ZSK9-ZSQ9	0.0586	ZSN9-ZSU9	0.0871
	ZSH9-ZSX9	0.0426	ZSN9-ZSQ9	0.0516	ZSU9-ZSX9	0.0726

Notes: This table reports volume shares for the five most-traded soybean outright and calendar spread contracts in three subperiods of the first half (H1) of calendar year 2019: Jan-Feb, Mar-Apr, and May-Jun. The contracts are rolled to the front month contract on the first position day (2 business days before the expiration month). Each soybean futures contract is for 5,000 bushels of soybean. Soybean futures contracts have seven maturities: January (F), March (H), May (K), July (N), August (Q), September (U), and November (X). When decoding the four-digit contract ticker, the first two digits (ZS) stand for "CBOT soybean futures"; the third digit is the contract month; and the fourth digit (9) indicates the contract year (2019 in this case). Trading hours during the sample period are from 8:30 a.m. to 1:20 p.m. CT. Source: CME Group and authors' computations.

Table A2: Volume Shares of the 5 Most-traded Contracts Soybean Contracts, H1-2020

	Jan-Feb		Mar-Apr		May-Jun	
	Contract	Share	Contract	Share	Contract	Share
Outright	ZSH0	0.5937	ZSK0	0.5401	ZSN0	0.6475
	ZSK0	0.2303	ZSN0	0.2892	ZSX0	0.2305
	ZSN0	0.0967	ZSX0	0.1071	ZSQ0	0.0570
	ZSX0	0.0642	ZSH1	0.0380	ZSH1	0.0358
	ZSH1	0.0151	ZSQ0	0.0256	ZSU0	0.0292
	Jan-Feb		**Mar-Apr**		**May-Jun**	
	Contract	Share	Contract	Share	Contract	Share
Calendar spread	ZSH0-ZSK0	0.4857	ZSK0-ZSN0	0.4482	ZSN0-ZSX0	0.3602
	ZSH0-ZSN0	0.1603	ZSN0-ZSX0	0.1335	ZSN0-ZSQ0	0.1483
	ZSK0-ZSN0	0.1049	ZSK0-ZSX0	0.0621	ZSQ0-ZSX0	0.0694
	ZSN0-ZSX0	0.0656	ZSX0-ZSH1	0.0450	ZSX0-ZSF1	0.0579
	ZSH0-ZSX0	0.0273	ZSX0-ZSF1	0.0438	ZSX0-ZSH1	0.0548

Notes: This table reports volume shares for the five most-traded soybean outright and calendar spread contracts in three subperiods of the first half (H1) of calendar year 2020: Jan-Feb, Mar-Apr, and May-Jun. The contracts are rolled to the front month contract on the first position day (2 business days before the expiration month). Each soybean futures contract is for 5,000 bushels of soybean. Soybean futures contracts have seven maturities: January (F), March (H), May (K), July (N), August (Q), September (U), and November (X). When decoding the four-digit contract ticker, the first two digits (ZS) stand for "CBOT soybean futures"; the third digit is the contract month; and the fourth digit (0) indicates the contract year (2020 in this case). Trading hours during the sample period are from 8:30 a.m. to 1:20 p.m. CT. Source: CME Group and authors' computations.

Appendix 2:

In this Appendix, we conduct robustness checks to verify that factors other than COVID-19 are unlikely to explain changes in market liquidity during the COVID-19 crisis in 2020. Similar to Ruan *et al*. (2021), we apply our model to additional recent years, creating a placebo COVID-19 dummy variable in the same time interval as the one we construct for 2020 and testing whether this artificial variable explains variations in market liquidity in those other years.

As explained in Section 4.3.d, we use the same kind of data as in our main analysis, taken this time from the first half of 2016 and of 2017 (rather than 2019 and 2020). We do so for soybean calendar spreads and outrights. We apply DOLS to the natural logarithm of the ratio of those two years—but this time reverse their ordering (2016/2017). We use the year 2017 as our benchmark given its low volatility (similar to 2019) and 2016 as our high-volatility year (similar to 2020). We create the artificial placebo dummy variable $PLACEBO_t$ based on the same time frame as the COVID-19 crisis in 2020. We set $COVID_t$ equal to one from the Thursday of the second week in February till the Thursday of the second week in April 2016, and to zero otherwise.

Table R1 displays the DOLS estimates of the impact of the placebo (i.e., the artificial COVID-19) variable on quoted bid-ask spreads (BAS) in the outright and calendar spread soybean futures markets during the day and night trading sessions, respectively[24]. Similar to Table 5, Panel A, the BAS is narrower amid greater volume and lower realized volatility (RV). The coefficient estimates for volume and RV using 2016 *vs*. 2017 ratios are similar in magnitude to those using 2020 *vs*. 2019 ratios. Crucially, unlike in Table 5A (2020 *vs*. 2019), the artificial COVID variable does not show any statistically significant power in explaining BAS variability in 2016 *vs*. 2017.

[24] For our robustness DOLS analysis using years 2016 and 2017, we find that a couple of outliers affect the normality of the residuals. We add dummy variables to restore normality. To make the comparison easier with our main (2020 *vs*. 2019) analysis, we do not report those dummies in Table R1; they are statistically significant.

Table R2 shows the DOLS estimates of the impact of the artificial COVID-19 variable on the top-of-book depth in the outright and calendar spread soybean futures markets during the day and night trading sessions, respectively. As expected, one finds higher depth when the trading volume is high and lower depth when the market is more volatile. Unlike the results for BAS, the magnitude of the absolute values of our coefficient estimates for the volume and realized volatility variables are in general higher for the year 2016 *vs*. 2017 (Table R2) than for the year 2020 *vs*. 2019 (Panel B in Table 5); the only exception is for volume in the calendar spread regression for the night session. Here too, the placebo COVID-19 variable is statistically insignificant in the calendar spread market (day and night sessions) and in the outright market (day session). Although the placebo variable increase is significant at the five percent level of confidence during the night session for the outright market, as shown in Panel B of Table 5, the sign is *positive*—whereas only a statistically significantly negative coefficient might indicate a potential problem.[25]

In sum, by applying our analysis to additional years of data, our placebo tests suggest that the effect of COVID-19 could not be explained by other factors during the same time frame. The fact of lacking significance for the placebo dummy variable suggests that there are no other factors in previous years that could explain the liquidity change during the COVID-19 pandemic.

Appendix 2 References:

Ruan, J., Cai, Q., & Jin, S. (2021). "Impact of COVID-19 and Nationwide Lockdowns on Vegetable Prices: Evidence from Wholesale Markets in China." *American Journal of Agricultural Economics.* Available at: https://doi.org/10.1111/ajae.12211

[25] Note that we do not find any statistically significant impact of the COVID-19 pandemic in the corresponding session during the COVID-19 crisis. As noted in the main text, this lack of significance may be an artifact of the generally low outright futures volume during the night session.

Table R1. DOLS Estimates of the Placebo COVID-19 Impact on Bid-Ask Spreads 2016/2017

	Outright		Calendar Spread	
	Day Session(k=4)	Night Session(k=4)	Day Session (k=2)	Night Session(k=3)
lnRatio_Vol$_t$	-0.042***	-0.189***	-0.037**	-0.145***
	(0.014)	(0.035)	(0.016)	(0.022)
lnRatio_RV$_t$	0.056***	0.179***	0.051***	0.172***
	(0.005)	(0.015)	(0.003)	(0.010)
PLACEBO$_t$	-0.001	-0.020	-0.006	0.009
	(0.007)	(0.016)	(0.009)	(0.019)
Roll	0.026	0.064**	-0.006	-0.050
	(0.017)	(0.026)	(0.010)	(0.048)
N	110	110	110	110
R^2	0.876	0.850	0.871	0.934
Normality (Jarque-Bera test)	2.770	0.945	0.104	7.555**
Residual Stationarity (KPSS)	0.081	0.087	0.057	0.062
Parameter Stability (CUMSUM)	0.712	0.620	0.387	0.699

Notes: This table presents Dynamic Ordinary Least-Squares (DOLS) estimates of the impact of the placebo COVID-19 crisis on quoted bid-ask spreads in the outright soybean futures and calendar spread markets during the day and night trading sessions. The right-hand side variables are: *lnVol_Ratio* is the natural logarithm ("log") of the trading volume ratio in 2016 (numerator) *vs*. 2017 (denominator); *lnRV_Ratio*$_t$ is the log of the realized volatility ratio in 2016 *vs*. 2017; trading days are matched each year to avoid day-of-week effects when computing the ratios. Daily values of BAS and RV are computed using volume-weighted averages across the top five most active contracts, as explained in Table 4. *PLACEBO* is a placebo dummy variable set equal to one between Thursday of the second week in February and April in 2016 and 2017 respectively, and zero otherwise. *Roll* is a dummy variable that equals one on the day after the prompt contract's first position day and zero otherwise. Heteroskedastic and autocorrelation robust standard errors are presented in parentheses. *, ** and *** denotes significance at the 10%, 5% and 1% levels, respectively. Sample period: January 11 to June 28, 2016 and matching days in 2017.

Table R2. DOLS Estimates of the Placebo COVID-19 Impact on Market Depth 2016/2017

	Outright		Calendar Spread	
	Day Session(k=4)	Night Session(k=4)	Day Session (k=1)	Night Session(k=1)
lnRatio_Vol$_t$	0.474***	0.506***	1.443***	1.008***
	(0.165)	(0.149)	(0.490)	(0.335)
lnRatio_RV$_t$	-0.805***	-0.657***	-0.596***	-0.784***
	(0.047)	(0.065)	(0.141)	(0.155)
PLACEBO$_t$	0.060	0.133**	0.056	-0.331
	(0.075)	(0.054)	(0.220)	(0.243)
Roll	0.070	-0.052	1.180*	1.076***
	(0.069)	(0.068)	(0.635)	(0.370)
N	110	110	110	110
R^2	0.952	0.919	0.425	0.405
Normality (Jarque-Bera test)	0.962	0.796	4.780*	2.919
Residual Stationarity (KPSS)	0.091	0.065	0.151	0.228
Parameter Stability (CUMSUM)	1.269***	0.602	1.075**	1.111**

Notes: This table presents Dynamic Ordinary Least-Squares (DOLS) estimates of the impact of the placebo COVID-19 crisis on the top-of-book quoted depth in the outright soybean futures and calendar spread markets during the day and night trading sessions. The right-hand side variables are: *lnVol_Ratio* is the natural logarithm ("log") of the trading volume ratio in 2016 (numerator) *vs*. 2017 (denominator); *lnRV_Ratio*$_t$ is the log of the realized volatility ratio in 2016 *vs*. 2017; trading days are matched each year to avoid day-of-week effects when computing the ratios. Daily values of BAS and RV are computed using volume-weighted averages across the top five most active contracts, as explained in Table 4. *PLACEBO* is a placebo dummy variable that equals one between Thursday of the second week in February and April in 2016 and 2017 respectively, and zero otherwise. *Roll* is a dummy variable that equals one on the day after the prompt contract's first position day and zero otherwise. Heteroskedastic and autocorrelation robust standard errors are presented in parentheses. *, ** and *** denotes significance at the 10%, 5% and 1% levels, respectively. Sample period: January 11 to June 28, 2016 and matching days in 2017.