CORRELATIONS GO TO ONE IN A CRISIS: DID THE COVID 19 MARKET CRASH BRING CATTLE FUTURES AND EQUITIES TOGETHER?

by

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ABSTRACT

This study investigates cattle futures response to the equities crash in March of 2020 and the subsequent COVID-19 linked production delays at beef packing plants. I observe that the initial declines in cattle futures began prior to the onset of beef packing plant shutdowns. Fitting a Vector Error Correction Model on live cattle futures, feeder cattle futures, and corn futures to the E-Mini S&P 500 futures contract finds evidence that the S&P 500 had a significant impact on cattle prices during March of 2020. These results are an example of increased cross-asset correlation during periods of financial distress.

CHAPTER 1. INTRODUCTION

The market adage "all correlations go to one in a crisis" refers to uniform financial market declines during periods of extreme volatility. This appeared to be true in March of 2020. Faced with unprecedented uncertainty at the onset of the COVID-19 pandemic, markets responded with sell-offs across many asset classes. For example, the E-Mini S&P 500 futures contract finished March down 21% from the beginning of the year. Similarly, the earliest cattle futures contracts in this study, December Live Cattle and August Feeder Cattle, fell 23% and 16% respectively, over the same period.

This decline in cattle futures prices was popularly attributed to the shutdown of beef packing plants due to COVID-19 outbreaks among plant workers (Bradbury, 2020). The earliest plant shutdowns occurred at the end of March and continued through the spring (Reuters, 2020). Weekly cattle slaughter numbers declined throughout April and reached a yearly low during the first week of May (Knight and Davis, 2020). However, as seen in figure 3.1 many of the initial drops in cattle futures came in mid-March, coincident with declines in global equities markets but prior to plant shutdowns. Research has shown that futures making up the cattle crush spread, which mimics the profitability of a cattle feedlot, offer good hedging effectiveness for producers. These futures are expected to correlate with fundamentals in the cattle market more than to events in the broader financial markets (Fei et al. 2021; Power and Vendev 2010; Haigh and Holt, 2002). This paper examines if cattle futures experienced increased co-movement with the S&P 500 during the time preceding, during and immediately after the March 2020 equity crash.

To examine this question, five-minute intraday futures data is used to estimate vector error correction models (VECM) on the E-Mini S&P 500 futures contract (ES) and the three futures making up the cattle crush spread: live cattle (LE), feeder cattle (GF), and corn (ZC). The relationship among these futures is studied in four time periods: before mid-February, during financial market turmoil in February through March, during the cattle processing plant shutdowns in April, and from May to July where cattle slaughter returned to 2019 levels (Knight & Davis, 2020). These periods were chosen based on price movements in figure 3.1 and due to important events in equity and cattle markets. Structural break tests run on cattle crush spread series calculated with equation 1 using the futures in the cattle crush spread confirm specific break dates between the periods described. If cointegration is found between ES and crush futures, then a

VECM is fitted, and ES futures are tested using a restriction test to determine if ES was a significant component of the crush spread during that period. If no cointegration is established, then no further tests are performed for that period. If ES futures do not enter an equilibrium relationship with the cattle crush spread, then that is considered evidence that the movements in cattle markets were not caused by increased correlation with financial markets. However, if it is found that ES futures do enter an equilibrium relationship with the cattle crush spread, the tests will not be able to identify whether it was caused by increased correlation among all asset classes or by a fluke of timing of traders' expectations over the impending slowdown of cattle slaughter capacity.

Much of the research on COVID-19's impact on agriculture has examined production slowdowns. In March and April of 2020 prices weakened across the beef supply chain and production backlogs led to increased feed costs and increased weights of cattle at each stage of production. (Martinez et al, 2020). Research on packing plants have found that prices paid to farmers for livestock decreased while the retail prices of meat rose (Lusk et al, 2020). In turn, United States agriculture exports dropped significantly in April 2020, with beef and other livestock products falling more than grain exports (Mallory, 2020).

This work builds on previous research on the impacts of economic events on commodity prices. Historically, research found commodities had negative correlations with equities and bonds (Gorton & Rouwenhourst, 2006). Analysis of potential drivers of the wheat prices from 1990 to 2011, with a focus on spikes from 2008 to 2011, found fundamentals were the primary drivers of wheat prices as opposed co-movements with outside markets (Janzen et al, 2014). A similar study on cotton futures from 2008 to 2011 also found that changes in cotton prices was due to market fundamentals instead of outside financial speculation (Janzen et al, 2018).

However newer research on commodity and equities co-movement finds increased correlation in recent decades, especially since the 2008 financial crisis (Delatte et al, 2013). Studies have found that co-movement may increase during times of financial distress (Buyuksahin et al, 2009; Girardi, 2015). Some attribute this "financialization of commodities" to index funds that directly invest in commodity futures (Masters, 2008; Tang and Xiong, 2010). Further research about commodity indices' effects on commodity prices do not find compelling evidence to support this index hypothesis (Irwin & Sanders, 2012.) The logic behind the "all correlations go to one" phenomenon is that as asset prices in a large market, such as equites fall, money managers facing losses in those assets may have to liquidate positions in other markets to cover potential margin calls[1]. Thus, asset classes that usually have low correlations can become extremely correlated if there is a sudden crash in a large market.

This study on the financialization of commodities distinguishes itself by observing the market effects of a force, COVID-19, that both caused a market collapse and directly disrupted the cattle supply chain. Many previous studies focus on fallouts from the 2008 global financial crisis where there were large drawdowns in equities prices as well as commodities prices, but the primary causes of these declines were not the same.

The results show that the initial drops in cattle futures, as well as much of the volatility in their prices, occurred prior to meat packing plant shutdowns. Cointegration tests find that cattle crush spreads futures and ES futures were cointegrated between February and March of 2020, with many of the spreads continuing to show cointegration through April. Afterwards, as cattle slaughter begins to pick back up cointegration with ES futures disappears in the period from May through July. Restriction tests on the VECM models find that ES futures influenced the movements of the cattle crush spread during the panic selling in March. Impulse response functions (IRFs) find that shocks in ES futures had statistically significant effects on live cattle, feeder cattle and corn futures. These findings of commodity co-movement during the March stock market crash is consistent with previous studies of market co-movement during financial distress.

[1] A margin call is when a bank or broker requires a trader to deposit more funds to cover previous losses in markets.

CHAPTER 2. BACKGROUND

SARS-CoV-2, better known as COVID-19, is a respiratory virus first identified in China at the end of 2019. After spreading across the globe, it was officially declared a pandemic by the World Health Organization on March 11th, 2020 (WHO, 2020). COVID-19 is primarily transmitted via aerosol droplets emitted when people cough, sneeze, or even talk (CDC). As of the end of 2021 there have been 290 million cases and over 5.4 million deaths (JHU, 2021**)** worldwide. The resulting crisis from this virus affected both the supply and demand for beef products.

The beef industry experienced significant disruptions across all stages of production, from individual cow/calf operators to large beef packing plants. Beef packing plants were especially susceptible to COVID-19 infections among their workers. These facilities employ a large staff who work in close proximity to one another and often lodge and commute together – increasing risk of transmission (Reuben, 2020). Additionally, packing plants are temperature controlled to be cold which makes it easier for the virus to survive (Reuben, 2020). The high risk and spread of COVID-19 resulted in 53,000 infections and 277 deaths of workers at US meat packing plants in the first year of the pandemic (Douglas, 2020**)**. As a result of the high number of COVID-19 cases among plant workers, plants experienced production slowdowns so severe that there were worries of a meat shortage (Kang, 2020). Former President Donald Trump signed an executive order designating meat packing workers “essential employees” to ensure that the plants could stay open and continue to process and supply beef (Faulders, 2020). Even with all the effort and sacrifice from workers, companies, and politicians it wasn’t until mid-June before cattle slaughter returned to 2019 levels (Knight & Davis, 2020).

While COVID-19 caused operational issues were most pronounced at beef packing plants the upstream parts of the beef supply chain were burdened as well. One of the primary ways feeder cattle are bought and sold are through auctions. Like other businesses, auction houses had to adjust to the pandemic and local restrictions which meant that many auctions didn’t occur or had to shift online (MacArthur, 2022). Research has found that weights increased for both feeder cattle and live cattle during the month of April in part due to the backlogs at cattle processing facilities and the interruption of feeder cattle auctions (Martinez et al, 2020).

The demand for beef also was seriously impacted by the COVID-19 lockdowns of many restaurants, in-person schools and large in-person events (Balagtas, 2021). COVID-19 restrictions largely drove down US spending on food away from home (FAFH). FAFH fell 32.6% in 2020. Food at home, food from grocery or convenience stores, rose 6.4% but total food spending fell 10.4% from 2019 (BLS, 2021). While these food categories include more than just beef, the Bureau of Labor Statistics' CPI for beef and veal expenditures in cities rose 9.6% in May of 2020 from April. This was higher than the increase for total food at home expenditures, signaling that these production setbacks resulted in higher meat prices for consumers (BLS, 2022). As the pandemic was a world event, other countries also saw less dining out and travel, so beef products did not have other marketplaces they could shift to make up for less demand. From 2019 to 2020 US exports of beef and veal fell 2.5% (FAS PSD).

2.1 Cattle feeding timeline

The cattle feeding sector is set up around a calf's life cycle. The number of operators at each level is shaped like a pyramid, thinning the farther downstream you go. Cow/calf operators that breed and raise calves are at the base with many farms across the United States. They are large in numbers but often small in herd size with an average herd size of 43.5 in 2017 (ERS). Cows have a roughly a 9-month gestation period with most operations set up for spring calving. This is done for them to have adequate time to graze on grass through the summer before being weaning in the fall. Once weaned calves begin the backgrounding stage. Where calves typically weighing 500 to 600 pounds are fed grain, silage, hay, or grass to increase their weight before being sold to a feed lot. Backgrounding takes 4-6 months and can be done by the cow/calf operator or a separate party (ERS). Once a calf reaches roughly 700-800 pounds in weight it can be moved on to a feedlot. Auctions are used to sell calves to both backgrounders and feedlots.

Feedlots represent the next step of the pyramid. This stage is much more scaled towards larger operations. Feedlots are primarily located in the in the corn belt and the great plains. Large feedlots with over 1,000 head of cattle finish up 80% of all cattle annually (ERS). When they arrive at the feedlots the animals are considered feeder cattle and are fed a ration of about 75% corn and 25% soybean meal or other protein to reach a weight of 1,000 to 1,500 pounds over the course of 4 to 6 months (ERS).

CME's Feeder Cattle futures contract (GF) is used to hedge risk for feedlots and backgrounders which is why it was chosen for this study. One feeder cattle futures contract represents 50,000 pounds of feeder steers weighing between 700 and 899 pounds. There are eight monthly feeder cattle contracts: January, March, April, May, August, September, October, and November. Each contract expires at the end of its trading month. Feeder cattle contracts are financially settled as opposed to being physically settled. This means that holding a contract to termination doesn't result in the delivery of physical feeder cattle but rather the contract holder either pays or is paid the difference between the original price when the futures contract was created and the futures price at termination (CME**)**. The price of feeder cattle futures are based on the CME Feeder Cattle Index. This index is generated using feeder cattle auction transactions reported to the Agricultural Marketing Service on a weekly basis in 12 states encompassing the great plains and rocky mountain regions of the US as seen in figure 2.1.

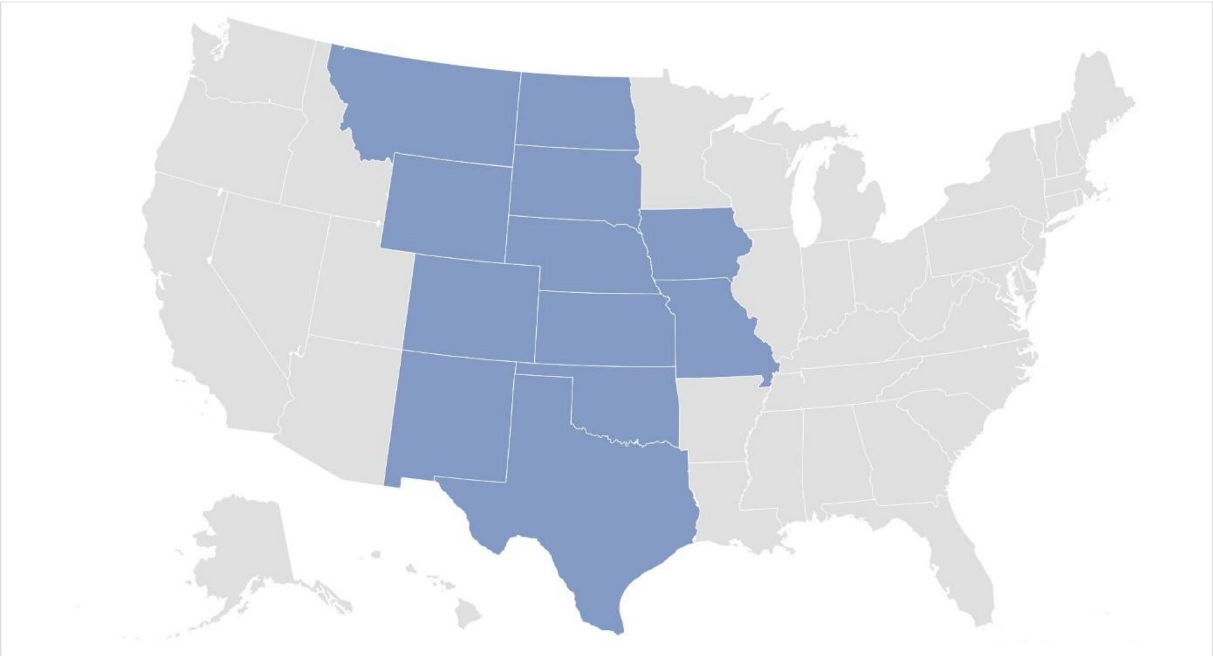

Figure 2.1: Map of States in the CME Feeder Cattle Index

Note: Figure 2.1 highlights 12 states listed left to right, top to bottom, are Montana, North Dakota, Wyoming, South Dakota, Nebraska, Iowa, Colorado, Kansas, Missouri, New Mexico, Texas, and Oklahoma.

Once cattle reach adequate weight (greater than 1,000 pounds) they are sold by feedlots to meat packers. Meat packers slaughter the cows and then fabricate their carcasses into a variety of primal cuts which then can be boxed and sold or ground for ground beef (Pruitt et al, 2013). This is the most concentrated sector of the beef supply chain and meat packing is dominated by four companies who together pack over 80% of the beef in the United States (Lusk, 2021).

CME Live Cattle futures (LE) contracts cover cattle (both steers and heifers) between 1,050 and 1,500 pounds and can be used by feedlots and the meat packers to manage price risks. This contract was chosen as the final cattle futures contract for the study. One contract represents 40,000 pounds of steers or heifers grading at 70% choice and 30% select. Choice and select are the primary grades that beef will grade as once it is boxed (Pruitt et al, 2013). Live Cattle futures are physically settled and have expiration months of February, April, June, August, October, and December. Each live cattle contract expires at the end of the month. Live cattle futures have more daily volume than feeders in this study.

In recent years there has been debate surrounding the usefulness of live cattle futures. The controversy at the center of this regards the non-convergence of futures and cash prices in the live cattle market. Cash and futures must converge for a futures market to be successful and the act of a short position holder delivering the commodity to the long position holder enforces this convergence. Over the last decade there has been a rise in "formula" priced agreement between feedlots and packers for the sale of live cattle. In these pricing agreements feedlots and packers negotiate prices in private as opposed to buying and selling out in the open on cash or futures markets. Cattle sold on formula sales effectively takes them out of delivery and reduces the need to hedge for those feedlots and packers involved. As of 2017 formula priced live cattle is how most live cattle are sold, meaning this private market is now the primary market for live cattle (Scroeder & Coffey, 2018). These increased formula sales have come mostly at the cost of cash sales. Allegations have been made that formula sales lessen the importance of cash and futures markets and thus the prices in cash and futures markets may not be the most accurate market prices for live cattle. (Clayton, 2021).

CHAPTER 3. DATA

3.1 Futures data

This study examines the E-Mini S&P 500 futures contract, as well as the live cattle, feeder cattle and corn futures contracts from the Chicago Mercantile Exchange and the Chicago Board of Trade. Live cattle, feeder cattle, and corn futures make up cattle crush spread. The study period runs from January 1st, 2020, to July 1*st*, 2020. July 1st is approximately when cattle slaughter numbers returned to their 2019 levels (Knight & Davis, 2020). Futures contracts that traded over the whole study period were chosen. Those contracts are December 2020, February 2021, and April 2021 live cattle contracts; August 2020 and October 2020 feeder cattle contracts; and September 2020 and December 2020 corn contracts. ES futures are rolling nearby futures with volume-based rolls and back-adjusted prices at the contract rollovers[2]. Although corn and ES contracts have overnight trading hours, all prices in our analysis are between 8:30 a.m. – 1:05 p.m., when live and feeder cattle contracts are traded. All analysis was performed with 5-minute data to capture intraday volatility. All futures contracts chosen for this study are the primary futures for their specific commodity category in terms of volume.

3.2 Commitment of traders data

Additionally, graphs are generated with data on large trader positions in futures markets from the Commodity Futures Trading Commission's (CFTC) commitment of traders report (COT). The CFTC requires traders in futures markets whose positions exceed a specific level in a market to report their positions and the nature of their business to the CFTC. This is done for all major futures markets, but this study focuses on COT reports for live and feeder cattle.

Traders are grouped into specific categories based on their primary business. The four categories are: producer/merchant, managed money, swap dealers and other reportables. Producers/merchants are any trader who produces or uses the commodity in a production process. Feedlots and beef packing plants are included in this category. Managed money includes hedge

[2] The data source for this research, barchart.com, changes ES future contracts expiration based on their calculation taking into account volume and open interest. They also adjust the price differences between the different expirations which is called a back adjustment.

funds and other speculators who never seek to take delivery of the commodity. Swap dealers are made up of commodity index funds and entities engaged in commodity-based financial swaps. Other reportables are traders that are not placed in the previous three groups. The CFTC estimates that positions reported from these four categories make up 70 to 90% of all open interest in markets at a time.

COT reports are released every Friday, but their data includes positions from the Tuesday of the previous week to the Tuesday of the same week as the Friday release. There is a large amount of information on these reports from the number of long and short positions opened to total amount of traders and open interest that week. This research only uses the percent of open interest for merchants and money managed long and short positions. Open interest is a measure of how many derivatives contracts are unsettled in a market. The research on the usefulness of COT reports in predicting prices is limited. In general, most research finds that COT reports are not helpful to forecast agricultural futures (Sanders et al, 2009), this study uses the COT data to provide context in the analysis of why cattle futures declined prior to packing plant shutdowns.

3.3 Motivations for research

Figure 3.1 displays the futures contracts that make up the cattle crush spread, along with the S&P 500 futures contract (ES). The cattle and corn (ZC) futures contracts experience a slow decline before the crash in late March, similar to the S&P 500. Packing plants began to shut down during the beginning of April which coincides with the second steep drop in the cattle prices on April 2nd (Reuters, 2020). Feeder cattle and live cattle futures quickly rebounded after this drop, while corn futures took until early summer before appreciating. Cattle futures rose through the rest of the April even though cattle slaughter was declining throughout April, reaching its lowest level in the first week of May (Knight & Davis, 2020). This rise suggests that markets expected the production bottlenecks to be overcome by the expirations of the feeder cattle (October 2020 and November 2020) and live cattle (December 2020, February 2021, and April 2021) contracts in this study.

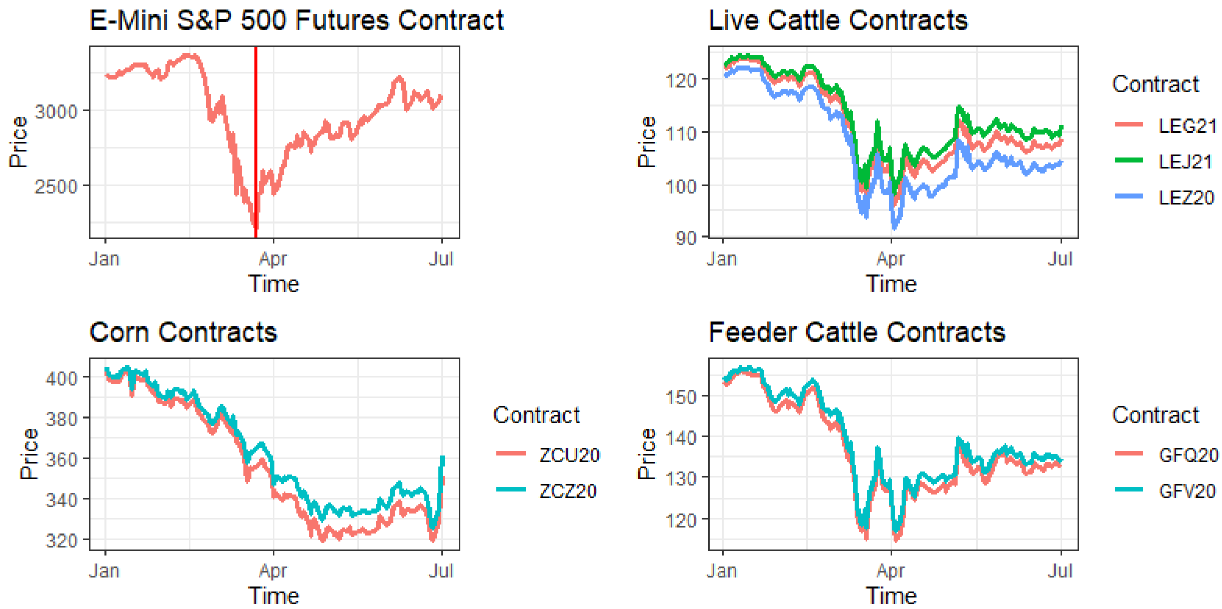

Figure 3.1: Graph of the cattle crush spread components and the E-Mini S&P 500 futures contract

Note: Figure 3.1 shows a rolling E-Mini S&P Futures contract, with the red line signifying the yearly low of the contract on 3/23. Clockwise from the ES, the next panel is of the three live cattle contracts included in the study: December 2020 (LEZ20) February 2021 (LEG21) and April 2021 (LEJ21). The bottom right panel shows the feeder cattle contracts: August 2020 (GFQ20) and October 2020 (GFV20). The final panel in the bottom left shows the two corn contracts in the analysis: September 2020 (ZCU20) and December 2020 (ZCZ20).

Figure 3.2 contains the money manager (MM) and producer positions in live cattle as a percentage of open interest and December 2020 live cattle futures prices. Figure 3.3 contains these same positions but for feeder cattle futures and August 2020 feeder cattle futures prices. Managed money positions are on the top, producer positions are in the middle and futures prices are on the bottom. The top two charts for these figures both contain COT information for the preceding week. For example, the data point just to the right of March 9th contains trader positions from Tuesday March 3rd through Monday March 9th. Futures prices on these charts are not structured this same way and include prices for the date listed.

Open interest (OI) counts how many unsettled, or "open" positions there are in a derivatives market. As every futures contract must have a buyer and a seller OI increases when new futures contracts are being entered into. OI decreases when positions are being exited and can remain constant if traders offset positions to other traders entering into the market. Trader positions as a percentage of OI tells us both, the positions that money managers and producers are taking in the market, and how much of the market's OI those positions constitute. COT reports are the best publicly available data to see the positions that market participants are taking.

Money manager positions and producer positions should be viewed differently. Money managers are mostly pure speculators as they are not involved in using the commodity. Their positions represent their view on where prices are going. Producers use the underlying commodities in their business practices, so their positions are likely mostly for hedging. However, as per CFTC rules if a business is considered a producer, then all their reported trades will be listed in the producer category even if they are more speculative in nature.

Overall, the graphs show that money managers had large and increasing short positions in cattle futures during February as futures prices fall. The managers began closing their shorts in mid-March when prices are near their lowest points likely to collect the gains they had made on their positions. At the end of April, money managers had more longs than shorts in both markets and prices had begun to pick back up. The exact reasoning for these manager's trades is unknowable but both money manager charts show them adding to their shorts in February to March, right as ES futures were falling as well. Producer charts in the figures aren't as similar as the money manager charts. Producers in live cattle markets appear to be mostly feedlots hedging against price increases in live cattle and the movements are less sharp and responsive to prices changes in live cattle futures than what is seen in the equivalent feeder cattle graph in figure 3.3. Price changes are more rapid and severe for feeder cattle producers, but the graph does seem to show feedlots locking prices during the lows in March and backgrounders hedging to prevent against any further losses in April.

MM positions are of particular interest to this research as it appears that they bet on lower cattle prices beginning in February as the S&P 500 was also declining. They then cashed out their positions at some of the lowest periods for cattle and ES futures in mid-March.

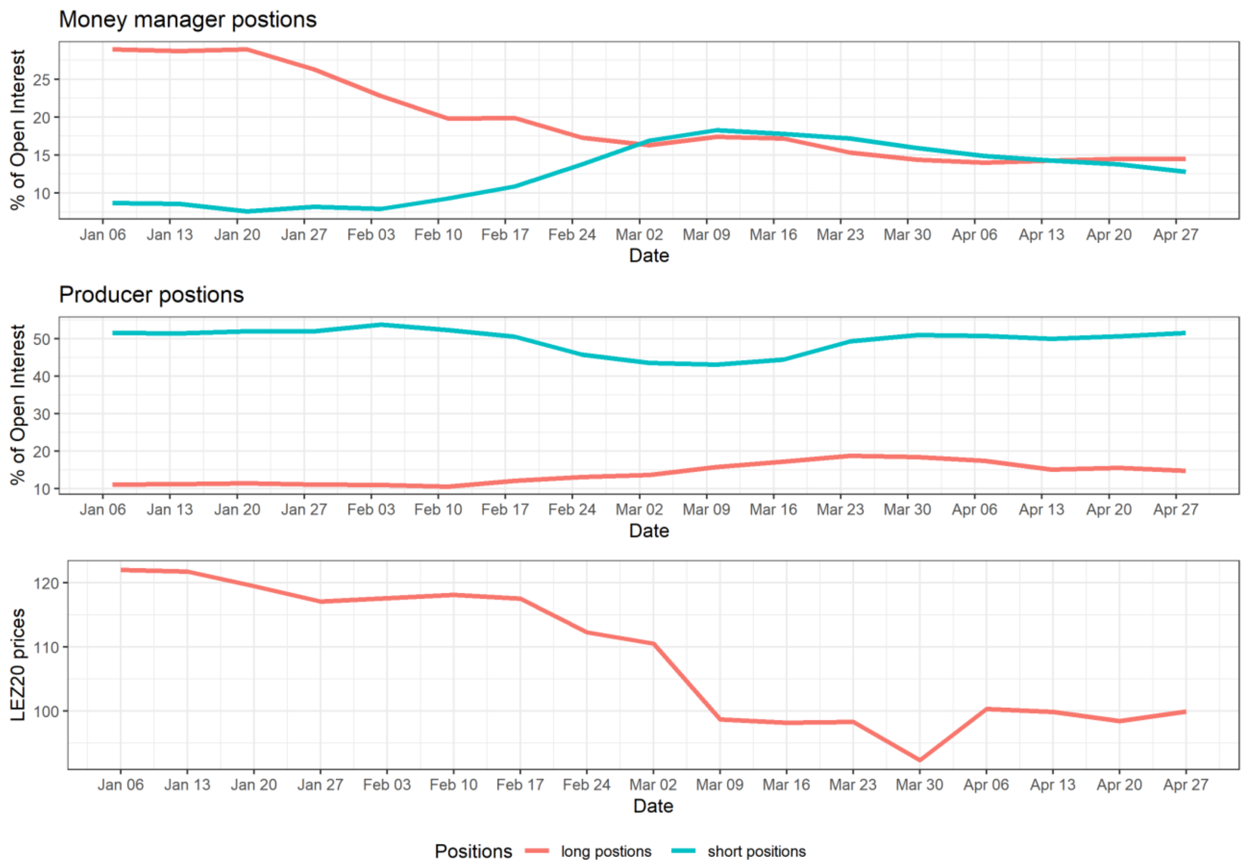

Figure 3.2: Chart of managed money (top) and producer (bottom) positions in live cattle Futures as percentage of open interest

Note: Figure 3.2 includes graphs of money manager positions as a percentage of open interest in live cattle futures (top), and producers' positions as a position of open interest in live cattle futures (middle). For both, the blue line shows short positions, and the red line shows long positions. The Y-axis is OI in percentage terms. The bottom chart is the December 2020 live cattle futures price over this same time period.

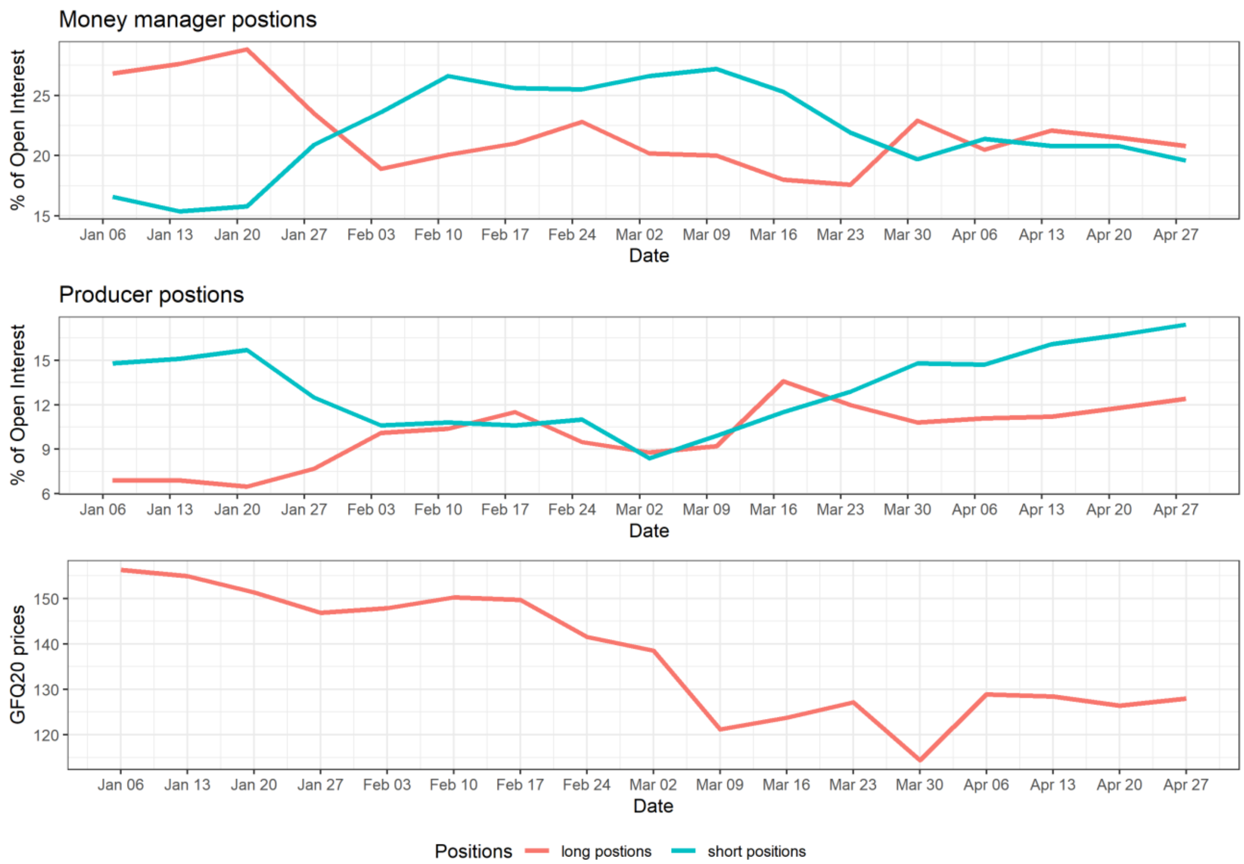

Figure 3.3: Chart of managed money (top) and producer (bottom) positions in feeder cattle futures as percentage of open interest

Note: Figure 3.3 includes graphs of money manager positions as a percentage of open interest in feeder cattle futures (top), and producers' positions as a position of open interest in feeder cattle futures (middle). For both, the blue line shows short positions, and the red line shows long positions. The Y-axis is OI in percentage terms. The bottom chart is the August 2020 feeder cattle futures price over this same time period.

CHAPTER 4. METHODOLOGY

The analysis proceeds as follows. First, three cattle crush spreads are constructed, each containing a live cattle, feeder cattle, and corn futures contract. The contracts are spaced out so that the expirations of the futures contracts in each spread mimic the production timeline for finishing a calf. Equation 1 below uses all three agricultural futures in each spread to calculate the profitability of finishing cows on a per head basis for 266 calves. This profitability series is called the cattle crush spread. Though the main analysis will utilize multi-equation models to determine the nature of the influence of ES futures on the cattle crush spread, the single series of the calculated cattle crush spread is used to conduct structural break tests to determine the subperiods used in the rest of the analysis.

After determining each series to be non-stationary, cointegration tests are conducted on each of the three cattle crush spreads and the nearby ES futures over the full sample, from January 1st to July 1st. As well as and during each individual subperiod created from the structural break tests. Then, if cointegration is found over the full sample or a subperiod a VECM is fitted for the time frame. The VECM model includes the three agricultural futures in each spread, live cattle, feeder cattle and corn as well as ES futures. A likelihood ratio restriction test on the VECM results is used to determine the significance of ES during each period.

The VECMs for the full sample of each spread are then transformed into their vector autoregressive model (VAR) representations. These transformations allow for further analysis on the relationship between cattle and ES futures in the form of impulse response functions (IRFs). All the analysis that is completed for the cattle crush spreads and ES futures is repeated using just the agricultural futures for each spread. This is done to serve as a robustness check on the full results. Comparing these results can highlight the effects of ES futures prices on the cattle crush spread.

4.1 Identifying Subperiods with Structural Break Tests on the 8-4-2 Cattle Crush Spread

The 8-4-2 cattle crush spread represents a gross profit equation for feedlots represented by live cattle revenue minus feeder cattle and corn costs (Steiner, 2014). This represents 8 live cattle contracts, 4 feeder cattle contracts and 2 corn contracts. The 8-4-2 spread is widely used in the industry as the proper spread for feedlot hedging, which is why it was chosen for this study. This combination can hedge approximately 266 calves entering feed lots at 750 lbs, marketed as live cattle at 1,250 lbs and fed 10,678 bushels of corn. The total is then divided by 266 to give the result on a per head basis.

$$Cattle\ Crush\ Spread\ Spread\ = \frac{(Live\ Cattle\ \$ * 8 * 400) - (Feeder\ Cattle\ \$ * 4 * 500) - (Corn\ \$ * 2 * 5000)}{266} \tag{1}$$

Feeder cattle contract expiration are chosen such that the feeder cattle contract expires between four and six months before the live cattle contract to allow for adequate time for the feeders to reach finished weight. Corn futures contracts are included in the spread to account for feeding costs. Finishing rations are about 75% corn and are purchased closer to the feeder cattle contact expiration. Since several expirations of the cattle spread were trading at the time of the March 2020 COVID-19 crisis, the spreads are named after the expiration of their live cattle contract. The spreads examined are December 2020, February 2021, and April 2021. These spreads and the futures that comprise them are in table 4.1. These spreads were chosen because each constituent contract was trading during the date range analyzed, January 1st, 2020, to July 1st, 2020.

Table 4.1: Make up of the cattle crush spreads

Name of Spread	Live Cattle Contract	Feder Cattle Contract	Corn Contract	ES Contract
December Spread	December (LEZ 2020)	August (GFQ 2020)	September (ZCZ 2020)	Nearby
February Spread	February (LEG 2021)	August (GFQ 2020)	September (ZCU 2020)	Nearby
April Spread	April (LEJ 2021)	October (GFV 2020)	December (ZCZ 2020)	Nearby

Note: This table shows the collection of futures contracts that form the three spreads in this study table. The ES futures contract is rolling and back adjusted for all three spreads.

As seen in table 4.1 the December and February spreads share the same feeder cattle and corn contract. It is important to note this sharing of contracts because it could lead to similar results from the December and February spreads. This sharing of contracts was unavoidable if each spread's feeder cattle contract was going to be four to six months in front of the live cattle contract. For the December spread, August is only four months in front of the December live cattle contract but the nearest other feeder cattle contract months, May and September, lie outside the four to six month window. And for the February spread, the August feeder cattle contract is six months prior.

Tests for structural breaks are run on each cattle crush series for each spread to divide the January to July period into four subperiods. This allows for close examination on the evolution of the relationship between the cattle crush spread futures and ES futures. The structural break tests used are empirical fluctuation tests described in Bai and Perron (2003), Bai (1997), and Zeileis et al. (2003). The structural break tests work by moving along the crush spreads and testing for structural breaks sequentially. Previous studies have used a similar approach to identifying structural breaks (Carter and Smith, 2007). Each spread has similar structural break dates, so the mode of the dates is chosen to establish subperiods, the results of the structural break tests are included in appendix A. The time periods are displayed in figure 4.1 and are defined as follows: January 1st to February 23rd, February 24th to March 18th, March 19th to April 29th and then April 30th to July 1st.

4.2 Discussion of the subperiods

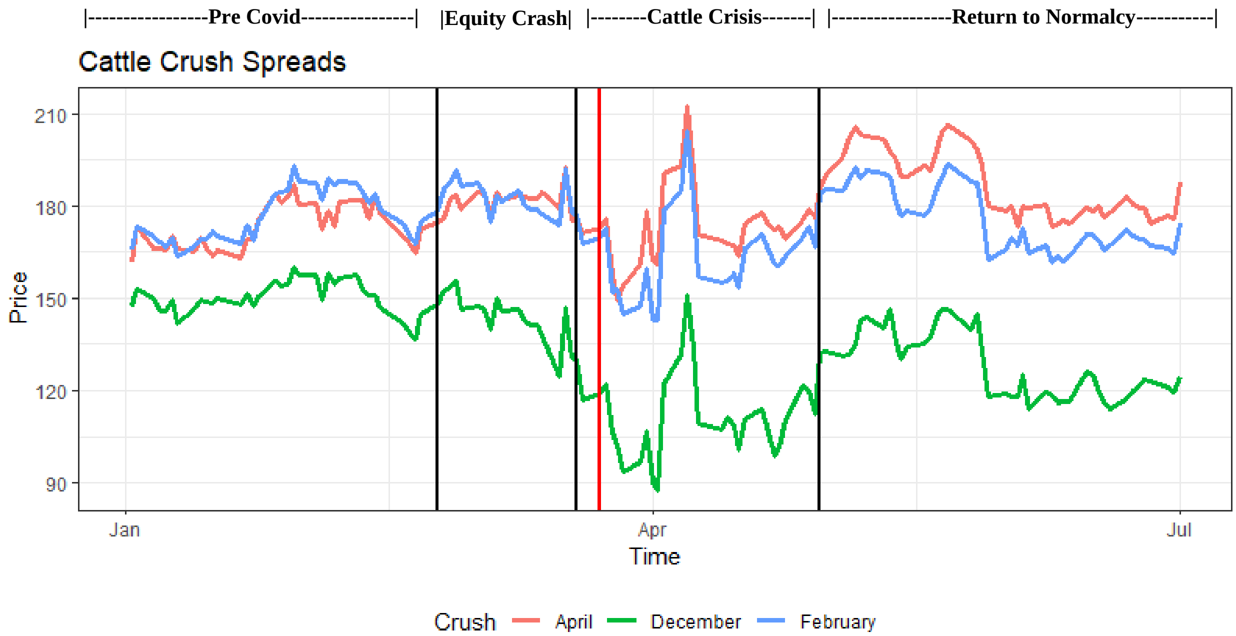

Figure 4.1: Graph of cattle crush spread breakpoints

Note: Breakpoints occurred on February 23rd, March 19th, and April 30th, shown as vertical black lines. The lines define the periods Pre Covid, Equity Crash, Cattle Crisis, and Return to Normalcy. The red line indicates the date of the bottom of the equity market crash for reference.

The first time period is "pre-COVID-19," in that while COVID-19 had already begun to spread in the United States it was not until March when the World Health Organization declared COVID-19 to be a pandemic (AJMC, 2020**)**. The second period is labeled "equity crash". The initial declines in equities and cattle markets occurred during this February to March period. It is important to notice that the March 19th breakpoint is very close to the bottom of the ES contract on March 23rd (figure 4.1). The third period is labeled "cattle crisis" as March and April included the bulk of the plant shutdowns. Finally, the fourth period is labeled "return to normalcy". Cattle slaughter numbers returned to 2019 levels in the April to July period (Knight & Davis, 2020) and equity markets began an impressive recovery from the March lows during this time. The primary focus is on the differences in the relationship between the cattle crush spread contracts and the ES contract between the February to March and March to April periods.

4.3 Determine Existence of Cointegration and Estimate VECM Models

First Augmented Dickey-Fuller, Phillips-Perron and KPSS tests are used to determine that all futures prices are non-stationarity. The results of these tests can be found in appendix A. Cointegration tests are conducted on the three agricultural contracts of each spread and the ES contact over the whole study period and across all four subperiods (Johansen, 1988; Johansen and Juselius, 1990). The agricultural futures in the cattle crush spread are expected to be cointegrated because the cattle futures are connected by production process as feeder cattle eventually become live cattle once they reach adequate weight. This connection between the contracts causes them to move conjointly overtime, as seen in figure 3.1. The ES is not traditionally a part of this relationship so cointegration tests on the full sample and the subperiods can determine if prices in the cattle spread moved in concert alongside the ES during the most volatile times of the crisis.

If the series are found to be cointegrated, a Johansen maximum likelihood estimation VECM is fitted to model these relationships, as shown below in equation 2. Lags for full sample and the subperiods of the spreads are selected using Bayesian Information Criteria. All spreads had between 1 and 4 lags. An exogenous dummy variable is included in the VECM as εD, called the "night" dummy**.** The value of εD is 1 when the time is 8:30am, when cattle futures open. This is done because cattle futures only trade from 8:30 am to 1:05 pm so there is a chance that the opening trade of a day is based more off external information that occurred between closing and opening than the previous day's closing price**.** A likelihood ratio test on a VECM without the dummy variable and a VECM with the dummy variable determined that VECM with εD is the proper model (Hareville, 1974). The results from this test are included in appendix A. The VECM includes an error correction term (ECT) with β terms that capture the relationship the series maintained. The α term precedes the ECT for each variable and determines how quickly prices return to equilibrium. The γ coefficients capture how lagged 5-minute returns of each variable affect the current price. Likelihood ratio Restriction tests are run on the ES β in each VECM equation to determine if it belongs in the VECM (Johansen, 1991).

$$
\begin{bmatrix} \Delta GF_t \\ \Delta LE_t \\ \Delta ZC_t \\ \Delta ES_{\ t} \end{bmatrix} = \begin{bmatrix} \gamma_0^{GF} \\ \gamma_0^{LE} \\ \gamma_0^{ZC} \\ \gamma_0^{ES} \end{bmatrix} + \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} [\beta_0 + \beta_1 GF_{t-1} + \beta_2 LE_{t-1} + \beta_3 ZC_{t-1} + \beta_4 ES_{t-1}] +
$$

$$
\begin{bmatrix} \gamma_1^{GF} & \gamma_1^{LE} & \gamma_1^{ZC} & \gamma_1^{ES} \\ \gamma_2^{GF} & \gamma_2^{LE} & \gamma_2^{ZC} & \gamma_2^{ES} \\ \gamma_3^{GF} & \gamma_3^{LE} & \gamma_3^{ZC} & \gamma_3^{ES} \\ \gamma_4^{GF} & \gamma_4^{LE} & \gamma_4^{ZC} & \gamma_4^{ES} \end{bmatrix} \begin{bmatrix} \Delta GF_{t-1} \\ \Delta LE_{t-1} \\ \Delta ZC_{t-1} \\ \Delta ES_{t-1} \end{bmatrix} + \begin{bmatrix} \gamma_1^{GF} & \gamma_1^{LE} & \gamma_1^{ZC} & \gamma_1^{ES} \\ \gamma_2^{GF} & \gamma_2^{LE} & \gamma_2^{ZC} & \gamma_2^{ES} \\ \gamma_3^{GF} & \gamma_3^{LE} & \gamma_3^{ZC} & \gamma_3^{ES} \\ \gamma_4^{GF} & \gamma_4^{LE} & \gamma_4^{ZC} & \gamma_4^{ES} \end{bmatrix} \begin{bmatrix} \Delta GF_{t-2} \\ \Delta LE_{t-2} \\ \Delta ZC_{t-2} \\ \Delta ES_{t-2} \end{bmatrix} +
$$

$$
\varepsilon D_1 + \begin{bmatrix} \vartheta_t^{GF} \\ \vartheta_t^{LE} \\ \vartheta_t^{ZC} \\ \vartheta_t^{ES} \end{bmatrix} \qquad (2)
$$

4.4 Vector Autoregressive Models

VAR representations of the previous VECM models are generated for the full sample of each spread. These VARs include the spread contracts and the rolling ES futures contracts. Orthogonal impulse response functions (IRFs) can be generated from the results of the VAR representation. Impulse response functions test how a shock to one variable in a VAR would affect another variable in a VAR. IRFs also check if assumptions on the relationship between the variables hold true and they display the magnitude and length of a shock (Lütkepohl & Poskitt, 1991). While IRFs appear to only model the aftermath of a positive shock from the shock variable this effect can be flipped to be a negative effect if the shock was negative.

CHAPTER 5. RESULTS

5.1 Cointegration test results

Results of cointegration testing are shown in table 5.1. All combinations of spreads and the S&P futures contract we analyze are cointegrated at a 1% significance level over the whole-time period of the study. All three spreads are cointegrated during the pre-COVID-19 period. Interestingly, even as cattle slaughter returned to previous levels, none of the spreads are cointegrated during return to normalcy period.

Table 5.1: Cointegration among cattle crush spread futures and the E-Mini S&P 500 futures contract

Spread	Full Sample	Pre-COVID-19	Equity Crash	Cattle Crisis	Return to Normalcy
December Spread	***	**	**	*	
February Spread	***	**	***	***	
April Spread	***	**	***	**	

Note: Null = series is not cointegrated; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level. Subperiod definitions: Pre-COVID-19, 1/01/2020-2/23/2020; Equity Crash, 2/24/2020-3/18/2020; Cattle Crisis, 3/19/2020-4/29/2020; Return to Normalcy, 4/30/2020-7/01/2020.

All three spreads are cointegrated at the 5% significance level or greater during the market crash period. The cattle crisis period contained some of the most severe production delays for beef packing plants. The April and February spreads are cointegrated to at least 5% significance level over this time. The December spread is cointegrated at the 10% significance level in this period as well.

The evidence of cointegration among all three spreads during the equity crash period supports my conclusions on the similar movements of ES and cattle futures in figure 3.1. These findings provide evidence supporting my co-movement hypothesis. Overall, the three spreads have very similar cointegration test results. These findings are examined this further by fitting VECM models to the subperiods in which ES, GF, LE, and ZC are cointegrated. The Johansen test results for table 5.1 can be found in appendix B

5.2 Cointegration results, without ES futures

The same cointegration tests were run on the just the live cattle, feeder cattle and corn contracts making up each spread to serve as a robustness check. The results of these tests are included as table 5.2. The full sample, equity crash and cattle crisis periods all have cointegration to at least the 5% level for each spread. A noticeable difference from these tests and the tests on the crush spread futures and the ES futures are that the December and February spreads both find cointegration in the return to normalcy period. None of the spreads in the full analysis were cointegrated over that time. Aside from this difference these findings are similar the results with the ES contract included. The cointegration test results for tables 5.1 and 5.2 are in appendix B.

Table 5.2: Cointegration among cattle crush spread constituents, without the E-Mini S&P 500 futures contract

Spread	Full Sample	Pre-COVID-19	Equity Crash	Cattle Crisis	Return to Normalcy
December Spread	**	*	***	**	**
February Spread	***	***	***	***	*
April Spread	***	***	***	***	

Note: Null = series is not cointegrated; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level. Subperiod definitions: pre-COVID-19, 1/01/2020-2/23/2020; Equity Crash, 2/24/2020-3/18/2020; Cattle Crisis, 3/19/2020-4/29/2020; Return to Normalcy, 4/30/2020-7/01/2020.

5.3 VECM error correction terms

Table 5.3 displays the β vector results from the VECMs of the cointegrated subperiods. There is a constant relationship between the feeder cattle (GF) β and the live cattle (LE) β across each period. This is unsurprising as the live cattle contract is composed of finished feeder calves, so if the price of one contract were to change, the other would likely move in the same direction in response. The constant β coefficients in the table represent a cattle crush value determined by the relationships among the futures in the series. These values are like the crush spread that can be calculated in equation 1. Based on these β coefficients the most profitable period to finish a calf was pre-COVID-19 and the declines in the cattle crush futures and ES futures drove down profitability during the equity crash. Profitability picks back up in the cattle crisis period but since none of the spreads are cointegrated during the final return to normalcy part of the study I can't see how crushing margins faired then. The constant β coefficients for the February and April spreads are more like one another than they are to the December spread which is surprising because the December and February spreads share the same feeder cattle and corn contracts.

Table 5.3: VECM β terms

Spread	Constant	GF	LE	ZC	ES
December					
Full Sample	-4.5	1	-1.25	0.03	-0.003
Pre-COVID-19	46.5	1	-2.01	0.15	-.005
Equity Crash	9.32	1	-1.34	0.02	-0.002
Cattle Crisis	14.63	1	-1.61	0.05	0.001
February					
Full Sample	13.89	1	-1.37	0.03	-0.003
Pre -COVID-19	96.13	1	-2.3	0.11	-0.003
Equity Crash	25.73	1	-1.32	-0.01	-0.004***
Cattle Crisis	59.49	1	-1.63	-0.02	-0.003
April					
Full Sample	23.58	1	-1.27	0.02	-0.004**
Pre-COVID-19	97.4	1	-2.17	0.06	-0.003
Equity Crash	-14.4	1	-1.52	0.17	-0.01***
Cattle Crisis	42.16	1	-1.7	0.02	-0.001

Note: Null = β is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

While small in magnitude, the ES β coefficients are consistent across each period. Due to the natural cointegration between the prices in the cattle crush spread, it is pertinent to check whether the ES is really a part of the equilibrium relationship by testing a restriction of $\beta_{ES} = 0$. When β_{ES} are significantly different from zero their β has asterisks in relation to the percentage level in table 5.3. Statistically significant β_{ES} are found in three instances: the β_{ES} for the February spread in the Equity Crisis subperiod, the β_{ES} for the April spread in the Equity Crisis subperiod, and the β_{ES} for the April spread in the full sample. The results of these tests confirm that ES futures had a significant impact on the cattle crush spread during the market declines in late February and March of 2020, but in none of the other subperiods considered aside from the full sample. This evidence of spillover from broader financial markets into cattle markets supports the visual analysis of figure 3.1, as well as the results of the cointegration tests where each spread was cointegration at least the 5% significance level during the equity crisis subperiod.

5.4 α terms from VECMs

Table 5.4 contains the α coefficients for the VECM equations. The α determines the speed at which the error correction term pushes prices back to equilibrium. If an α is found to be significant in an equation of the VECM model, then that price is contributing to pushing the group back into equilibrium. Overall, it appears that the feeder cattle α is often significant meaning that feeder cattle contracts will move to maintain the cattle crush spread's equilibrium. Some of the ES α's are found to be significant during the equity crash. This is unexpected as one would not expect the ES α to have a large role in maintaining the cattle crush spread but it follows the results of the restriction tests for the ES βs. At the same time only the April feeder cattle α is significant for the equity crash even though each spread's full sample α's are significant to at least the 5% level. This can be interpreted as a break down in cointegration during the volatile February-March period and perhaps the ES α coefficient's significance is a sign that ES futures influence on the cattle crush spread rose during the equity crash as seen from the restriction tests in ES β's in table 5.3.

Table 5.4: VECM α terms

Spread	GF	LE	ZC	ES
December				
Full Sample	-0.02***	-0.004	0.001	0.15
	(0.004)	(0.003)	(0.006)	(0.1)
Pre-COVID-19	-0.018*	0.01	-0.04	-0.22
	(0.01)	(0.01)	(0.02)	(0.14)
Equity Crash	-0.04	0.03	0.04	1.89*
	(0.03)	(0.02)	(0.03)	(0.91)
Cattle Crisis	-0.04**	-0.01	-0.01	-0.36
	(0.01)	(0.01)	(0.02)	(0.23)
February				
Full Sample	-0.02***	-0.004	-0.001	0.13
	(0.01)	(0.003)	(0.01)	(0.11)
Pre-COVID-19	-0.02	0.02*	-0.05	-0.38
	(0.01)	(0.01)	(0.03)	(0.21)
Equity Crash	-0.07	0.03	0.05	2.4*
	(0.04)	(0.02)	(0.04)	(1.11)
Cattle Crisis	-0.05**	-0.04	-0.003	-0.18
	(0.02)	(0.01)	(0.02)	(0.29)
April				
Full Sample	-0.03**	-0.003	0.02**	0.34
	(0.01)	(0.01)	(0.01)	(0.19)
Pre-COVID-19	-0.13	0.07	-0.14	-0.17
	(0.07)	(0.05)	(0.15)	(1.26)
Equity Crash	-0.15*	0.07	0.01	4.41*
	(0.07)	(0.05)	(0.07)	(2.19)
Cattle Crisis	-0.05*	0.02	-0.001	-0.39
	(0.02)	(0.02)	(0.03)	(0.42)

Note: Null = α is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

5.5 VAR generated orthogonal impulse response functions

Impulse response graphs are included in figures 5.1-5.4 and were generated from the VARs for the full sample of each spread. These individual plots show how the response variable changes in accordance with a one standard deviation move in the impulse variable. While they appear to only model the aftermath of a positive shock from the shock variable this effect can be flipped to be a negative effect if the shock was negative. These IRFs find that ES futures had statistically significant effects on several cattle futures in the study. Additionally, these IRFs show live cattle futures affecting feeder cattle futures but not the other way around.

IRF plots where ES futures are the impulse variable are shown in figure 5.1. There are nine total graphs as each column include the plots for the agricultural contracts in a spread: beginning with the December spread on the left and then the February spread in the middle with the April spread on the far right. Each IRF in a figure displays a variable's impact, called the impulse variable, on another variable, the response variable. The red line shows this impact and the gray zone around this line represents the 95% confidence interval for an effect. If the confidence interval includes the zero line, the effect is not statistically significant (Lütkepohl & Poskitt, 1991).

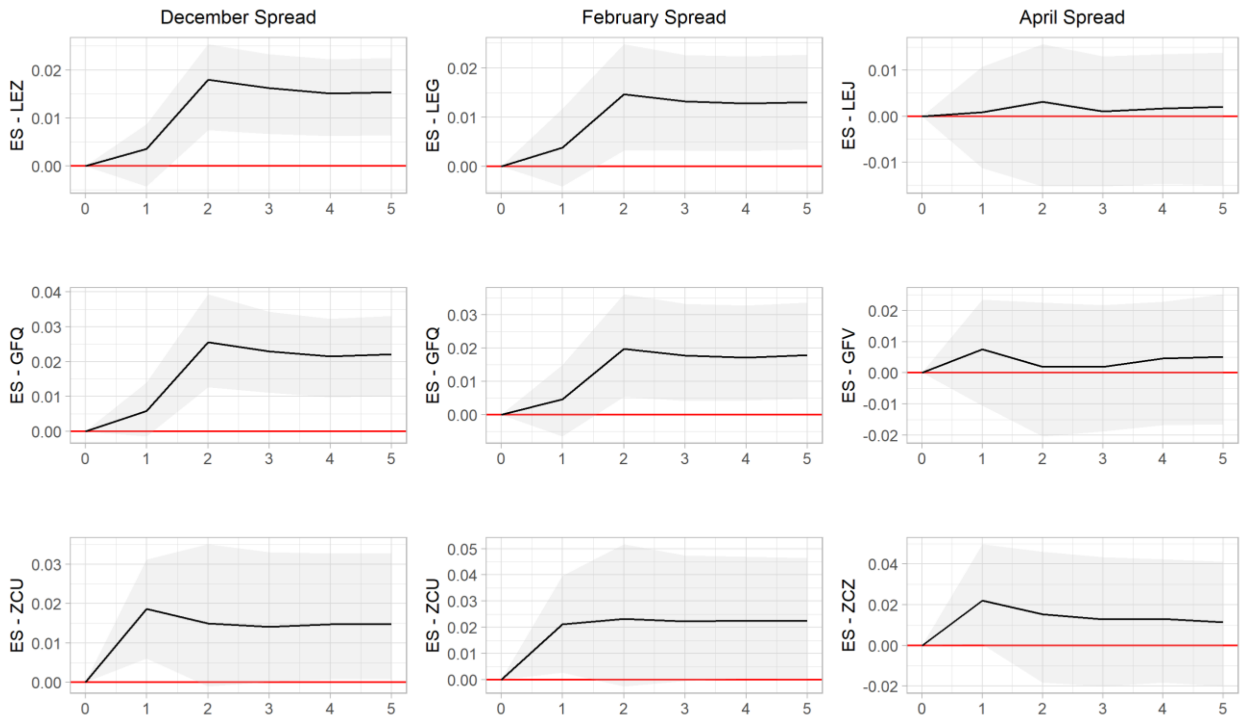

Figure 5.1: Orthogonal impulse response function plots from the full VARs with ES futures as the impulse

Note: This graph shows IRFs for ES futures as the impulse on all the other futures contracts in the study. The columns represent the three spreads with December, February and April shown left to right. Each row is a specific futures contract with live cattle in the top row, feeder cattle in the middle and corn futures on the bottom.

The top row in figure 5.1 includes the graphs of ES's impulse the three live cattle futures. Feeder cattle contracts are in the middle row and plots ES on the corn futures are in the last row. Both December and February live cattle futures have statically significant effects from ES futures starting on lag two (which would be 10 minutes as the data intervals are 5 minutes). The feeder cattle futures graphs in figure 5.1 mimic the movements and significance of their respective live cattle futures graphs. This could be because the December and February spreads both contain the August feeder cattle contract. These spreads also contain the same corn contract, September, both show the lag for corn as significant. None of the April spread's IRFs are statistically significant. The ES on the December and February feeder and live cattle futures demonstrate that a shock to ES results in a movement in these cattle futures that peaks 10 minutes after the shock and the effect lasts several lags. This follows previous evidence of ES futures acting upon cattle futures

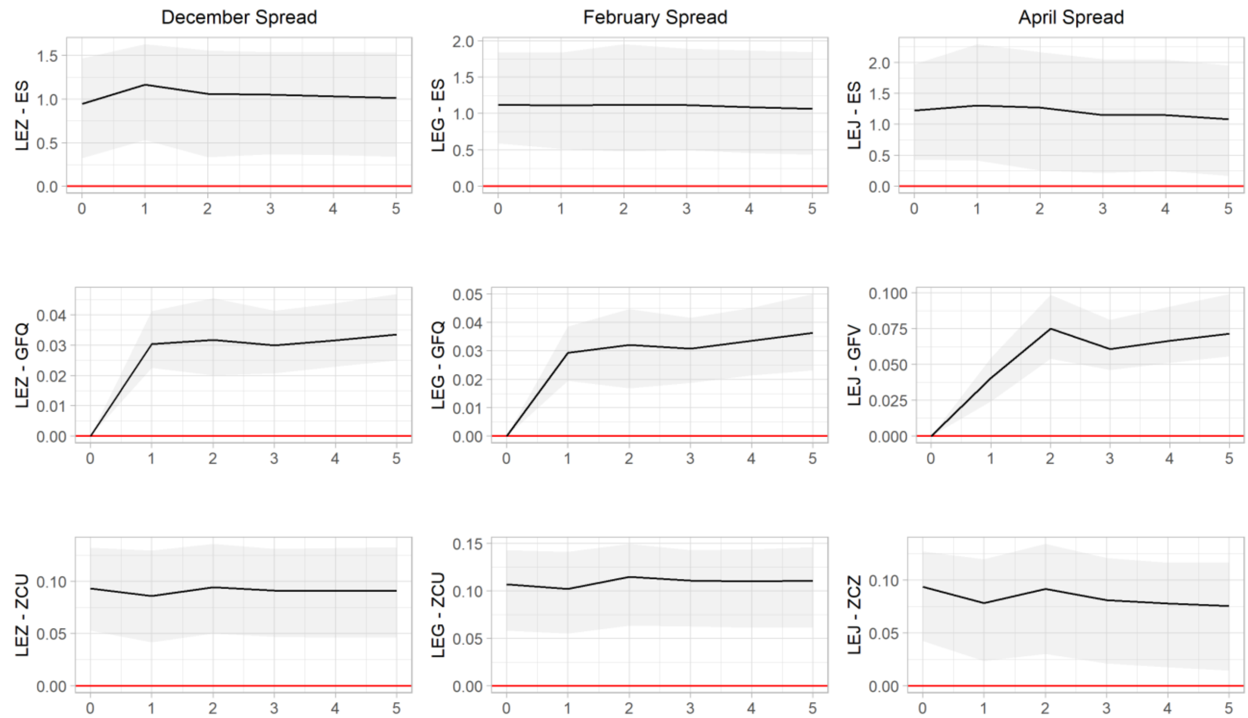

Figure 5.2: Orthogonal impulse response function plots from the full VARs with live cattle futures as the impulse

Note: This graph shows IRFs for live cattle futures as the impulse on all the other futures contracts in the study. The columns represent the three spreads with December, February and April shown left to right. Each row is a specific futures contract with ES futures on the top row, feeder cattle in the middle and corn futures on the bottom.

IRFs where live cattle are the impulse variable are in figure 5.2**.** Once again, the contents of each spread are in the columns and in chronological order left to right. Live cattle on ES IRFs are at the top, live cattle on feeder cattle are in the middle and the final row are live cattle on corn. The IRFs for each contract are similar across each spread. ES and corn IRFs are both essentially flat lines meaning that shocks in live cattle are contemporaneous to the shocks in ES and corn markets. IRFs can struggle to capture these contemporaneous effects as they impact both markets simultaneously and, in this case, the IRFs don't detail any movements corn or ES contracts could take (Lütkepohl & Poskitt, 1991). The lack of movement seen in ES and corn futures in response to a shift in live cattle futures is unsurprising. Live cattle futures are somewhat esoteric and aren't expected to be impactful for other non-cattle futures. On the other hand, a positive shock in live cattle does cause a quick statistically significant increase in feeder cattle which is also expected as they are linked markets and follows economic intuition as an increase in live cattle prices makes feeder cattle prices more valuable.

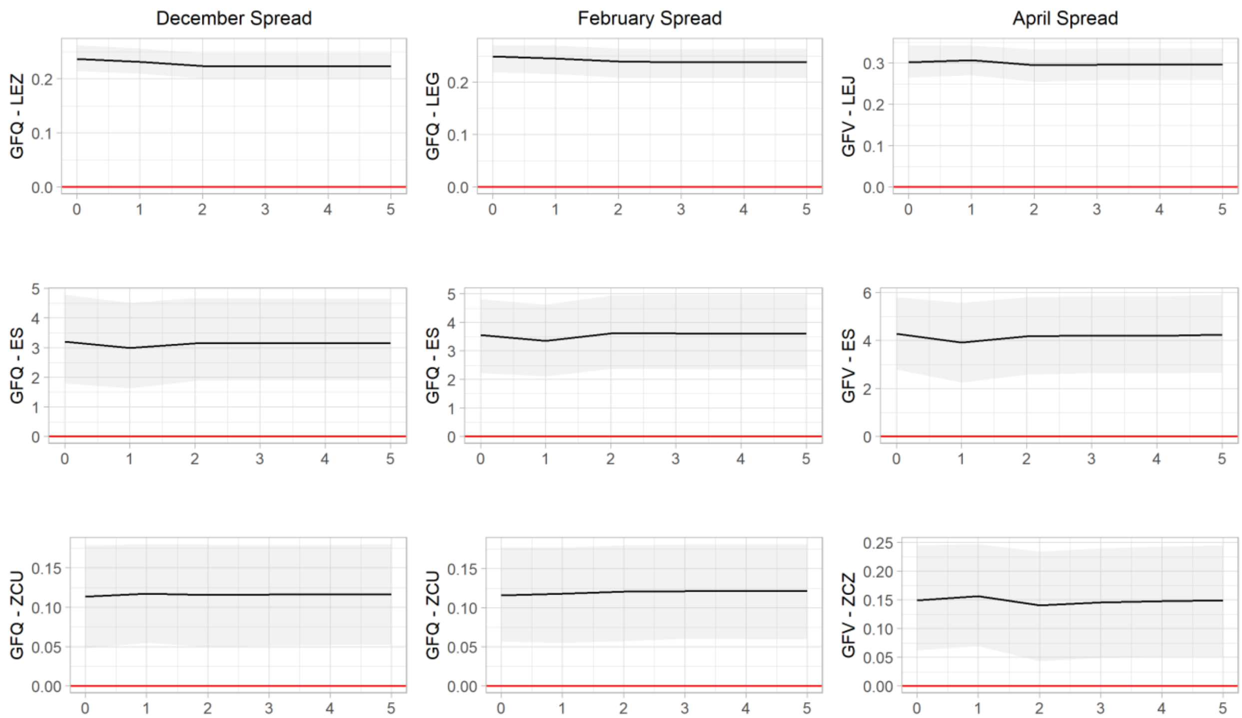

Figure 5.3: Orthogonal impulse response function plots from the full VARs with feeder cattle futures as the impulse

Note: This graph shows IRFs for feeder cattle futures as the impulse on all the other futures contracts in the study. The columns represent the three spreads with December, February and April shown left to right. Each row is a specific futures contract with live cattle in the top row, ES futures in the middle and corn futures on the bottom.

IRFs for feeder cattle on the other futures are above figure in 5.3. All the IRF plots here are flat lines in response to a shock in feeder cattle, signaling that the shocks from feeder cattle futures are contemporaneous for other futures. As stated earlier contemporaneous effects can result in flat line plots. While feeder cattle are not expected to impact ES or corn markets it is sensible to anticipate live cattle futures responding to shocks in feeder cattle. The lack of response from live cattle to feeder cattle stands in contrast to some of the results from the feeder cattle α's in the VECM model. If an α in a VECM is significant then that signals that variable is the one that moves other prices back into equilibrium. The α's for the feeder cattle contracts were significant for the full sample of all three spreads and these two contracts represent two of the main developments of a beef cows live cycle. So, it is surprising that the IRFs here show contemporaneous effects as opposed to specific movement like seen for live cattle on feeder cattle in figure 5.2. The contemporaneous effects seen for these IRFs could be related to the low volume in feeder cattle contracts relative to live cattle. Possibly, anytime there is a shock event for cattle markets actors in those markets express their views in the more liquid live cattle market.

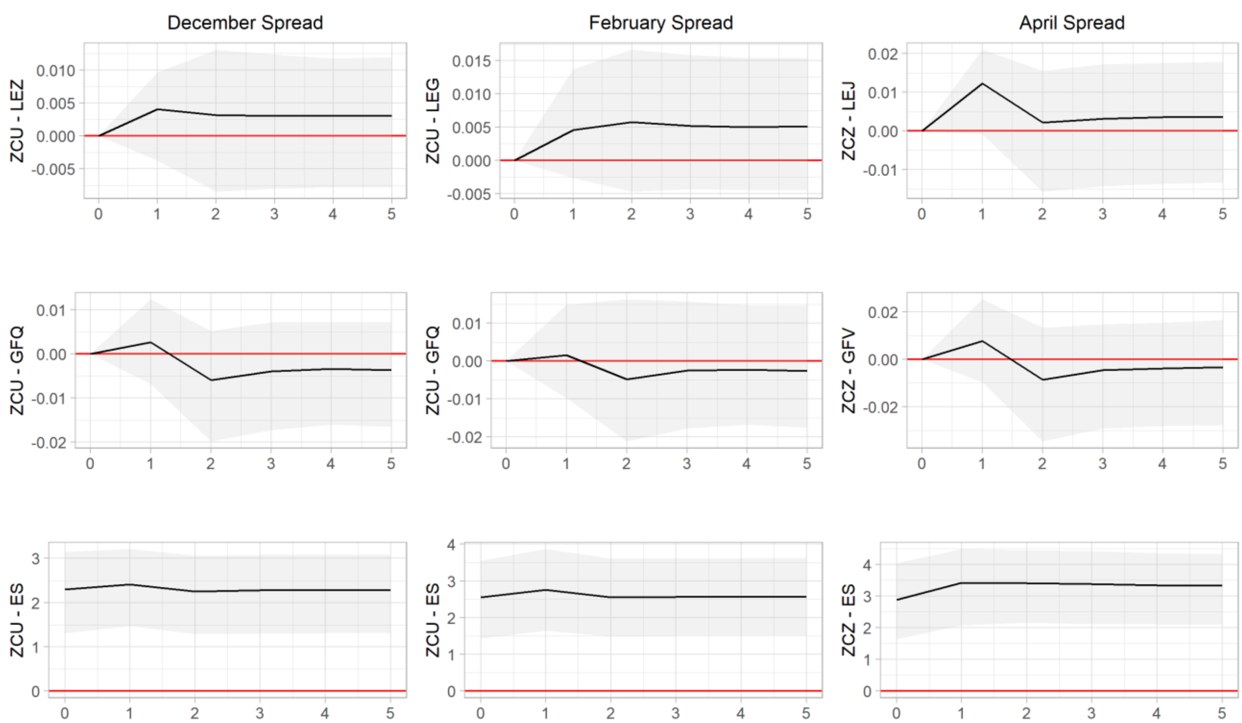

Figure 5.4: Orthogonal impulse response function plots from the full VARs with corn futures as the impulse

Note: This graph shows IRFs for corn futures as the impulse on all the other futures contracts in the study. The columns represent the three spreads with December, February and April shown left to right. Each row is a specific futures contract with live cattle in the top row, feeder cattle in the middle and ES futures on the bottom.

Figure 5.4 is the last of the IRFs and it contains graphs for corn on the other variables. The last row shows corn on ES futures and again these IRFs show contemporaneous effects. Despite their lack of significance, the IRFs for corn on the futures in the December and February spreads are again very alike. Aside from the ES IRFs no other variables show significant responses from a shock in corn in futures. This is unexpected as corn prices are a major input for finishing cattle so increases in corn prices should cause drops in feeder and live cattle prices.

CHAPTER 6. CONCLUSION

This study has examined relationship between futures in the cattle crush spread at all expirations actively traded during the first half of 2020 and ES. This analysis has found that the ES formed an equilibrium relationship with the cattle crush spread components during both the equity crash and cattle crisis sub-periods for all cattle crush spreads considered. Results from restriction tests on the β_{ES} coefficients suggest that cattle futures responded to changes in the S&P 500 during the equities crash in March 2020. Impulse response functions with ES futures as the impulse variable show that a shock from ES futures has a statistically significant effect on live cattle and feeder cattle futures. The statistical tests performed support the visual analysis of figure 3.1 where cattle futures decline alongside the ES contract beginning in February and drop substantially on March 19th, just two trading days before the ES yearly low on March 23rd. Cattle futures then experience large fluctuations in March but appear to normalize as April progresses even amidst declining cattle slaughter rates. The results of this research are consistent with prior findings of commodity and equity co-movement during periods of financial stress.

The conclusions from the results have some limitations. Studying cattle markets during the COVID-19 crisis is unique in that the same force that caused the market crash also had serious and immediate implications for the beef supply chain. While in previous economic crises the shock events typically did not directly impact agriculture supply chains. Therefore, it is nearly impossible to definitively identify whether the cattle crush contracts became cointegrated with ES contracts because there were simply financial market volatility spillovers, which is the idea behind the saying that all correlations go to one in a crisis, or whether market participants accurately predicted problems in the beef supply chain that led to price reaction in those markets predating the actual processing facility closures. The COT reports containing producer's positions in cattle markets don't show any movements that would signal that the producers were anticipating large declines in cattle futures. Rather it all looks like standard hedging. My view is that it is more likely that the cattle markets were experiencing increased correlation with equity markets during the period of increased (downside) volatility from February to March. However, this research cannot prove or disprove this directly; it is an important topic for future research.

This research also has implications for policy. I cannot provide an exact an answer to whether the cattle cointegration with ES markets was due to increased correlation during a period of volatility, or whether it was due to a group of informed traders correctly anticipating trouble with the cattle market. What is seen in figures 3.2 and 3.3 is that money managers built large short positions in both cattle futures markets in February before closing them around the lows in March. It is impossible to know what exactly these money managers were thinking when they made these trades but their timing with ES futures declines does fit the "all correlations go to one in a crisis" hypothesis. More detailed trading records that are available to regulators could shed more light what exactly money managers were doing at this time. This information could give further explanation on why cattle prices fell prior to plant closures. COVID-19 falls in the category of unexpected shocks to supply or demand that are extremely rare (like, for example, the fire at the Tyson's Holcomb, KS plant), and policy makers could consider whether there should be requirements for reporting to the public such material market information before placing trades. This would be similar in sprit to the Export Sales reporting system implemented after the 1970's purchases of large amounts of U.S. grain (Schmitz 2003).

APPENDIX A. STATIONARY TEST AND LIKELIHOOD RATIO TEST RESULTS

Table A.1: December Spread Stationary Test Results

statistic	p.value	parameter	method	alternative
-1.393437	0.8352694	18	Augmented Dickey-Fuller Test	stationary
-5.471198	0.8046467	11	Phillips-Perron Unit Root Test	stationary
33.835129	0.01	11	KPSS Test for Level Stationarity	unit root
-1.753134	0.6829172	18	Augmented Dickey-Fuller Test	stationary
-6.829112	0.7289505	11	Phillips-Perron Unit Root Test	stationary
30.586947	0.01	11	KPSS Test for Level Stationarity	unit root
-0.425215	0.9853091	27	Augmented Dickey-Fuller Test	stationary
-3.48099	0.9126588	15	Phillips-Perron Unit Root Test	stationary
115.8758	0.01	15	KPSS Test for Level Stationarity	unit root
-2.557856	0.3405211	46	Augmented Dickey-Fuller Test	stationary
-11.49423	0.4746023	22	Phillips-Perron Unit Root Test	stationary
345.70673	0.01	22	KPSS Test for Level Stationarity	unit root

Note: the null hypothesis of a augmented Dickey-Fuller test and a Phillips-Perron tests is that the series is non-stationary, the alternative hypothesis states that the series is stationary. The null hypothesis for a KPSS test is that the series is stationary, and the alternative hypothesis is that the series is non-stationary.

Table A.2: February Spread Stationary Test Results

statistic	p.value	parameter	method	alternative
-1.610967	0.7431077	17	Augmented Dickey-Fuller Test	stationary
-6.455613	0.7497467	10	Phillips-Perron Unit Root Test	stationary
20.76482	0.01	10	KPSS Test for Level Stationarity	unit root
-1.753134	0.6829172	18	Augmented Dickey-Fuller Test	stationary
-6.829112	0.7289505	11	Phillips-Perron Unit Root Test	stationary
30.586947	0.01	11	KPSS Test for Level Stationarity	unit root
-0.425215	0.9853091	27	Augmented Dickey-Fuller Test	stationary
-3.48099	0.9126588	15	Phillips-Perron Unit Root Test	stationary
115.8758	0.01	15	KPSS Test for Level Stationarity	unit root
-2.557856	0.3405211	46	Augmented Dickey-Fuller Test	stationary
-11.49423	0.4746023	22	Phillips-Perron Unit Root Test	stationary
345.70673	0.01	22	KPSS Test for Level Stationarity	unit root

Note: the null hypothesis of a augmented Dickey-Fuller test and a Phillips-Perron tests is that the series is non-stationary, the alternative hypothesis states that the series is stationary. The null hypothesis for a KPSS test is that the series is stationary and the alternative hypothesis is that the series is non-stationary.

Table A.3: April spread stationary results

statistic	p.value	parameter	method	alternative
-4.297549	0.01	25	Augmented Dickey-Fuller Test	stationary
-27.24253	0.016328	14	Phillips-Perron Unit Root Test	stationary
57.913279	0.01	14	KPSS Test for Level Stationarity	unit root
-2.911746	0.1920942	21	Augmented Dickey-Fuller Test	stationary
-12.37265	0.4201293	12	Phillips-Perron Unit Root Test	stationary
8.105555	0.01	12	KPSS Test for Level Stationarity	unit root
-1.408411	0.8302007	34	Augmented Dickey-Fuller Test	stationary
-3.373871	0.9175847	18	Phillips-Perron Unit Root Test	stationary
64.4846	0.01	18	KPSS Test for Level Stationarity	unit root
-2.557856	0.3405211	46	Augmented Dickey-Fuller Test	stationary
-11.49423	0.4746023	22	Phillips-Perron Unit Root Test	stationary
345.70673	0.01	22	KPSS Test for Level Stationarity	unit root

Note: the null hypothesis of a augmented Dickey-Fuller test and a Phillips-Perron tests is that the series is non-stationary, the alternative hypothesis states that the series is stationary. The null hypothesis for a KPSS test is that the series is stationary and the alternative hypothesis is that the series is non-stationary.

Table A.4**:** Likelihood ratio rests on VECMs with and without εD dummy variable

Name of Spread	Degrees of freedom	Test statistic	P-value	Result
December Spread	4	57.08	.001***	Use model with εD
February Spread	4	91.06	001***	Use model with εD
April Spread	4	42.72	001***	Use model with εD

Note: The null hypothesis of a likelihood ratio test means use the nested model (model without εD) and a result that rejects the null hypothesis means the model with εD is chosen

Table A.5**:** Structural break tests results

Name of spread	First structural break	Second structural break	Third structural break	Forth structural break
December Spread	2/14/20	3/20/20	4/30/20	5/28/20
February Spread	2/24/20	3/19/20	4/30/20	5/28/20
April Spread	2/24/20	3/19/20	4/30/20	5/28/20
Chosen breaks	2/24/20	3/19/20	4/30/20	null

Note: Empirical fluctuation tests are run to establish the breaks. The mode of the structural breaks was chosen to determine the sub period ranges. Even though a fourth structural break occurs on 5/28/20 this break was not included in the research as it was outside the core study periods.

APPENDIX B. COINTEGRATION TEST RESULTS

Table B.1: Johansen Cointegration test results for the December spread

Rank	Full Sample	Pre-COVID-19	Equities Crash	Cattle Crisis	Return to Normal	10%	5%	1%
r <= 3	3.3	1.75	4.04	5.96	2.2	7.52	9.24	12.97
r <= 2	7.56	4.13	9.26	8.86	12.12	13.75	15.67	20.2
r <= 1	21.01	10.67	11.12	15.61	14.39	19.77	22	26.81
r = 0	31.94	28.7	38.84	27.81	24.46	25.56	28.14	33.24

Note: The full sample has two cointegrated relationships found at the 10% level. Pre-COVID-19 has one cointegrated relationship at the 5% level, the Equities Crash period has one cointegrated relationship to the 1% level, Cattle Crisis has one cointegrated relationship at the 10% level and no cointegrated relationships are found in the return to normalcy period.

Table B.2: Johansen Cointegration test results for the February spread

Rank	Full Sample	Pre-COVID-19	Equities Crash	Cattle Crisis	Return to Normal	10%	5%	1%
r <= 3	3.66	2.11	4.04	6.19	2.24	7.52	9.24	12.97
r <= 2	7.35	5.66	9.26	9.03	12.54	13.75	15.67	20.2
r <= 1	21.02	11.21	11.12	16.03	15.82	19.77	22	26.81
r = 0	34.81	31.28	38.84	34.43	21.76	25.56	28.14	33.24

Note: The full sample has two cointegrated relationships found at the 10% level. Pre-COVID-19 has one cointegrated relationship at the 5% level, the Equities Crash period has one cointegrated relationship to the 1% level, Cattle Crisis has one cointegrated relationship at the 1% level and no cointegrated relationships are found in the return to normalcy period.

Table B.3: Johansen Cointegration test results for the April spread

Rank	Full Sample	Pre-COVID-19	Equities Crash	Cattle Crisis	Return to Normal	10%	5%	1%
r <= 3	4.15	1.85	4.57	6.87	2.43	7.52	9.24	12.97
r <= 2	13.75	4.66	8.5	9.29	12.52	13.75	15.67	20.2
r <= 1	19.84	8.33	12.43	13.54	17.31	19.77	22	26.81
r = 0	35.85	29.76	46.94	31.39	17.76	25.56	28.14	33.24

Note: The full sample has two cointegrated relationships found at the 10% level. Pre-COVID-19 has one cointegrated relationship at the 5% level, the Equities Crash period has one cointegrated relationship to the 1% level, Cattle Crisis has one cointegrated relationship at the 5% level and no cointegrated relationships are found in the return to normalcy period.

Table B.4: Johansen Cointegration test results for the December spread, without ES futures

Rank	Full Sample	Pre-COVID-19	Equities Crash	Cattle Crisis	Return to Normal	10%	5%	1%
r <= 2	3.66	1.69	2.25	2.76	5.01	7.52	9.24	12.97
r <= 1	12.79	6.62	9.32	8.86	11.88	13.75	15.67	20.2
r = 0	26.67	21.9	27.73	26.22	22.27	19.77	22	26.81

Note: The full sample has one cointegrated relationship found at the 5% level. Pre-COVID-19 has one cointegrated relationship at the 10% level, the Equities Crash period has one cointegrated relationship to the 1% level, Cattle Crisis has one cointegrated relationship at the 5% level and one cointegrated relationship is found in the return to normalcy period at the 5% level.

Table B.5: Johansen Cointegration test results for the February spread, without ES futures

Rank	Full Sample	Pre-COVID-19	Equities Crash	Cattle Crisis	Return to Normal	10%	5%	1%
r <= 2	5.01	2.03	2.34	2.67	5.7	7.52	9.24	12.97
r <= 1	11.6	7.92	9.27	9	13.56	13.75	15.67	20.2
r = 0	30.68	29	30.68	32.47	21.76	19.77	22	26.81

Note: The full sample has one cointegrated relationship found at the 1% level. Pre-COVID-19 has one cointegrated relationship at the 1% level, the Equities Crash period has one cointegrated relationship to the 1% level, Cattle Crisis has one cointegrated relationship at the 1% level and one cointegrated relationship is found in the return to normalcy period at the 10% level.

Table B.6: Johansen Cointegration test results for the April spread, without ES futures

Rank	Full Sample	s	Equities Crash	Cattle Crisis	Return to Normal	10%	5%	1%
r <= 2	8.31	1.3	2.35	2.7	6.46	7.52	9.24	12.97
r <= 1	15.36	6.31	9.14	8.72	13	13.75	15.67	20.2
r = 0	29.47	28.25	29.12	28.74	17.48	19.77	22	26.81

Note: The full sample has two cointegrated relationships found at the 10% level. Pre-COVID-19 has one cointegrated relationship at the 1% level, the Equities Crash period has one cointegrated relationship to the 1% level, Cattle Crisis has one cointegrated relationship at the 1% level and no cointegrated relationships are found in the return to normalcy period.

APPENDIX C. Β TERMS FOR VECMS WITHOUT ES FUTURES

The β's for the error correction terms of the VECMs run on cattle crush futures without ES futures are in table C.1. The live cattle and corn β values are very similar to the those in the VECMs in table 4. The most noticeable difference between the β's for the VECMs with ES and those without is within the constant value. When ES futures are included the profitability of calf finishing is slightly higher than when it is left out over each spread's full sample.

Table C.1: VECM β terms, without ES futures

Spread	GF	LE	ZC	Constant
December				
Full Sample	1	-1.4199	0.064399	-6.6842
Pre-Covid-19	1	-2.13515	0.209716	21.06088
Equities crash	1	-1.40387	0.003224	15.36527
Cattle crisis	1	-1.59719	0.036591	19.02169
Return to normalcy	1	-1.67654	-0.14819	90.07753
February				
Full Sample	1	-1.51807	0.051209	13.86586
Pre-Covid-19	1	-2.37895	0.137495	83.73602
Equities crash	1	-1.44959	-0.02712	36.34679
Cattle crisis	1	-1.70376	0.017546	43.32607
Return to normalcy	1	-1.56695	-0.13903	81.79887
April				
Full Sample	1	-1.48812	0.022757	21.49716
Pre-Covid-19	1	-2.2252	0.097281	80.83361
Equities crash	1	-1.70439	0.152302	-2.39425
Cattle crisis	1	-1.75925	0.020773	49.85264

Note: **Bold – s**ignifies statistically different from zero result in restriction tests on the ES coefficients.

APPENDIX D. Γ COEFFICIENTS FOR VECMS

Tables D1. through D.27 check below contain the γ coefficients or lags for all VECM models in the study. Lags for VECMs on cattle crush spread contracts and ES futures are in tables D.1 to D.12. Lags for VECMs featuring only the cattle crush spread futures without ES futures are in tables D.13 to D.27. The tables should be read left to right. The rows represent the VECM equation for the futures contract in the first column in a specific row. The second column in each row is always the α for that future's VECM equation and these values line up with the α's in table 5.4. Each column after the second column corresponds to one of the futures in the spread and that column contains all the lags that variable has in each VECM equation. If a lag is found to be significant then that means the lag is statistically important to determining the current price of whichever futures the VECM equation is for.

As this study is focused on how ES futures affected cattle markets the ES lags on live cattle and feeder cattle are of most importance. For the full sample December spread VECM, the second ES lag for live cattle and feeder cattle is significant to the 1% level. Similarly, the February spread full sample VECM finds the second ES lag for its live cattle futures to be significant to the 5% level. No ES lags on cattle futures are significant for the April spread. Additionally, the dummy variable representing to opening trades is often found to be significant to at least the 5% level for many of the futures in the full sample and across the sub periods for each spread. This backs up the likelihood ratio tests seen in figure A.4 that determined that it would be included.

Sticking with the focus on ES lags on the cattle futures, the results for the equity crash VECMs don't follow those in the full sample VECMs. Even though ES lags are found to be significant for some live and feeder cattle futures over the full sample no ES lags are significant for either cattle futures during any of the spread's equity crash period. This goes against expectations and previous findings expressing evidence of increased co-movement between ES and cattle futures during this time. Results from our other focus period, the cattle crisis period, show that the VECM equations for live cattle futures find the first lags for live cattle and feeder cattle futures to be significant to just the 10% level for the December and February spreads. The April spread's live cattle equation finds live cattle and feeder cattle lags significant to the 1% level during this time. The VECM equation for feeder cattle has no significant lags for any spread in the cattle crisis. This contrasts with results in the full sample where all VECM equations on feeder cand live cattle find their own lags as well as the lags of the other cattle contract to be significant.

The lags for VECMs on just cattle crush contracts with out ES futures are in tables D.13 through D.26. The lags in the VECMs for each spread's full sample and all subperiods are much alike to their counterpart VECMs that included ES futures. Most of the differences here are related to the degree of significance of the lag. The most interesting observation that can be made using these tables relates to the fact that cointegration is found for the return to normalcy periods for the December and February spread. This allows for VECMs to be generated for these periods. The VECM equations for live cattle and feeder cattle in this return to normalcy period are similar to the results from the full samples and show that live cattle and feeder cattle lags are again statistically significant for one another. I interpret this to mean that the cattle market is stabilizing here.

Overall, the lags don't provide much further help in the purpose of determining the impact of ES futures on cattle markets. The full sample results tell us that ES lags are significant for live cattle in two spreads, and feeder cattle in one spread. Confusingly though, no ES lags are significant for the cattle futures in the equities crash period for any of the spreads. Also, despite sharing the same feeder cattle and corn contract the lags for the December and February spreads are not as alike as expected based on their previous β's or α's.

Table D.1: VECM gamma coefficients for the December full sample

	Alpha	GFQ -1	LEZ -1	ZCU -1	ES -1
GFQ	-0.016*** (0.004)	-0.186*** (0.025)	0.198*** (0.038)	0.002 (0.009)	0.001 (0.001)
LEZ	-0.004 (0.003)	0.025 (0.017)	-0.074** (0.025)	0.006 (0.006)	0.001 (0.001)
ZCU	0.001 (0.006)	0.009 (0.037)	-0.02 (0.057)	-0.031* (0.013)	0.002* (0.001)
ES	0.145 (0.096)	-1.335* (0.557)	1.788* (0.847)	0.339 (0.201)	-0.041** (0.014)

	GFQ -2	LEZ -2	ZCU -2	ES -2	Dummy
GFQ	-0.097*** (0.025)	0.05 (0.038)	-0.024** (0.009)	0.002*** (0.0006)	-0.1** (0.037)
LEZ	0.005 (0.017)	-0.055* (0.025)	-0.008 (0.006)	0.002*** (0.001)	-0.136*** (0.025)
ZCU	-0.036 (0.037)	0.089 (0.056)	-0.041** (0.013)	-0.001 (0.001)	-0.407*** (0.056)
ES	0.462 (0.556)	0.221 (0.844)	-0.09 (0.201)	-0.044** (0.014)	0.529 (0.832)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.2: VECM gamma coefficients for the December pre-COVID-19 period

	Alpha	GFQ -1	LEZ -1	ZCU -1	ES -1	Dummy
GFQ	-0.018*	-0.11***	0.117*	-0.028**	-0.001	-0.034
	(0.008)	(0.033)	(0.056)	(0.011)	(0.002)	(0.032)
LEZ	0.006	0.091***	-0.214	-0.005	0.001	-0.13***
	(0.005)	(0.02)	(0.033)***	(0.006)	(0.001)	(0.019)
ZCU	-0.037	0.078	0.065	-0.039	0.002	- 0.551***
	(0.02).	(0.078)	(0.131)	(0.025)	(0.004)	(0.076)
ES	-0.224	-0.544	1.235	-0.083	-0.072**	2.481***
	(0.135)	(0.537)	(0.904)	(0.174)	(0.025)	(0.524)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.3: VECM gamma coefficients for the December equity crisis period

	Alpha	GFQ -1	LEZ -1	ZCU -1	ES -1	Dummy
GFQ	-0.07	-0.199**	0.379***	-0.039	0.001	-0.59***
	(0.036)	(0.068)	(0.103)	(0.039)	(0.001)	(0.141)
LEZ	0.033	-0.011	0.043	-0.017	0.001	-0.45***
	(0.024)	(0.046)	(0.066)	(0.026)	(0.001)	(0.096)
ZCU	0.049	0.107	-0.095	-0.123**	0.004**	-0.57***
	(0.04)	(0.074)	(0.113)	(0.043)	(0.002)	(0.155)
ES	2.388*	-2.113	7.5051*	-0.162	-0.108*	-26.71**
	(1.111)	(2.077)	(3.149)	(1.204)	(0.044)	(4.328)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% leve

Table D.4: VECM gamma coefficients for the December cattle crisis period

	Alpha	GFQ -1	LEZ -1	ZCU -1	ES -1	Dummy
GFQ	-0.039**	-0.058	-0.003	0.034	-0.002	0.27*
	(0.013)	(0.057)	(0.088)	(0.025)	(0.002)	(0.123)
LEZ	-0.007	0.087*	-0.143*	0.022	-0.001	0.18*
	(0.008)	(0.038)	(0.058)	(0.016)	(0.001)	(0.08)
ZCU	-0.015	0.137*	-0.235*	-0.062*	0.004*	-0.44**
	(0.015)	(0.068)	(0.105)	(0.029)	(0.002)	(0.145)
ES	-0.356	1.697	-4.503**	1.171**	-0.021	15.113***
	(0.231)	(1.042)	(1.61)	(0.449)	(0.03)	(2.22)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.5: VECM gamma coefficients for the February full sample

	Alpha	GFQ -1	LEG -1	ZCU -1	ES -1
GFQ	-0.019***	-0.158***	0.164***	0.001	0.001
	(0.005)	(0.026)	(0.04)	(0.01)	(0.001)
LEG	-0.004	0.06***	-0.131***	0.006	0.001
	(0.003)	(0.017)	(0.026)	(0.006)	(0.001)
ZCU	0.001	-0.001	-0.011	-0.033*	0.002*
	(0.008)	(0.039)	(0.06)	(0.015)	(0.001)
ES	0.132	-0.299	0.047	0.471*	-0.044**
	(0.115)	(0.583)	(0.903)	(0.219)	(0.015)

	GFQ -2	LEG -2	ZCU -2	ES -2	Dummy
GFQ	-0.091***	0.05	-0.017	0.002	-0.09*
	(0.026)	(0.04)	(0.01)	(0.001)	(0.041)
LEG	0.018	-0.064*	-0.002	0.001**	-0.121***
	(0.017)	(0.026)	(0.006)	(0.001)	(0.027)
ZCU	-0.043	0.111	-0.039**	0.001	-0.442***
	(0.039)	(0.06)	(0.015)	(0.001)	(0.06)
ES	0.442	0.61	-0.183	-0.027	0.912
	(0.581)	(0.999)	(0.219)	(0.015)	(0.906)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.6: VECM gamma coefficients for the February pre-COVID-19 period

	Alpha	GFQ -1	LEG -1	ZCU -1	ES -1	Dummy
GFQ	-0.017	-0.043	0.042	-0.026	-0.001	-0.028
	(0.013)	(0.045)	(0.074)	(0.015)	(0.002)	(0.046)
LEG	0.019*	0.163***	-0.225***	0.007	-0.001	-0.14***
	(0.008)	(0.026)	(0.044)	(0.009)	(0.001)	(0.027)
ZCU	-0.049	0.044	-0.034	-0.049	0.003	-0.646***
	(0.03)	(0.102)	(0.17)	(0.034)	(0.005)	(0.104)
ES	-0.384	-0.636	0.521	0.096	-0.038	2.902***
	(0.209)	(0.72)	(1.195)	(0.24)	(0.034)	(0.733)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant

Table D.7: VECM gamma coefficients for the February equities crash crisis period

	Alpha	GFQ -1	LEG -1	ZCU -1	ES -1	Dummy
GFQ	-0.07	-0.199**	0.379***	-0.039	0.001	-0.587***
	(0.036)	(0.068)	(0.103)	(0.039)	(0.001)	(0.141)
LEG	0.033	-0.011	0.043	-0.017	0.001	-0.454***
	(0.025)	(0.046)	(0.07)	(0.027)	(0.001)	(0.096)
ZCU	0.049	0.107	-0.095	-0.123**	0.004**	-0.574***
	(0.04)	(0.074)	(0.113)	(0.043)	(0.001)	(0.155)
ES	2.388*	-2.113	7.505*	-0.163	-0.108*	-26.71**
	(1.111)	(2.077)	(3.149)	(1.204)	(0.044)	(4.328)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant

Table D.8: VECM gamma coefficients for the February cattle crisis period

	Alpha	GFQ -1	LEG -1	ZCU -1	ES -1	Dummy
GFQ	-0.05**	-0.054	-.001	0.028	-0.003	0.271*
	(0.016)	(0.058)	(0.089)	(0.025)	(0.002)	(0.123)
LEG	-0.004	0.0823*	-0.145*	0.016	-0.002	0.18*
	(0.01)	(0.038)	(0.058)	(0.017)	(0.001)	(0.081)
ZCU	-0.003	0.071	-0.116	-0.055	0.003	-0.513***
	(0.019)	(0.068)	(0.105)	(0.03)	(0.002)	(0.146)
ES	-0.179	1.188	-3.475*	1.019*	-0.019	16.161***
	(0.289)	(1.05)	(1.623)	(0.462)	(0.031)	(2.244)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant

Table D.9: VECM gamma coefficients for the April full sample

	Alpha	GFV -1	LEJ -1	ZCZ -1	ES -1
GFV	-0.027**	-0.172***	0.169***	0.008	0.001
	(0.008)	(0.031)	(0.046)	(0.013)	(0.001)
LEJ	-0.003	0.137***	-0.235***	0.017*	-0.001
	(0.006)	(0.021)	(0.031)	(0.009)	(0.001)
ZCZ	0.02	0.016	-0.032	-0.029	0.002
	(0.012)	(0.043)	(0.065)	(0.018)	(0.001)
ES	0.345	-1.211	0.496	0.775**	-0.005
	(0.187)	(0.683)	(1.027)	(0.28)	(0.019)

	GFV -2	LEJ -2	ZCZ -2	ES -2	Dummy
GFV	-0.17***	0.241***	-0.023	-0.001	-0.096
	(0.031)	(0.046)	(0.013)	(0.001)	(0.055)
LEJ	-0.032	0.049	-0.012	0.001	-0.119**
	(0.021)	(0.031)	(0.009)	(0.001)	(0.037)
ZCZ	-0.062	0.077	-0.006	-0.001	-0.367***
	(0.043)	(0.064)	(0.018)	(0.001)	(0.078)
ES	0.375	0.831	0.339	-0.077***	1.481
	(0.683)	(1.008)	(0.28)	(0.019)	(1.226)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.10: VECM gamma coefficients for the April pre-COVID-19 period

	Alpha	GFV -1	LEJ -1	ZCZ -1	ES -1	Dummy
GFV	-0.125	-0.052	-0.036	-0.071	0.002	-0.057
	(0.074).	(0.126)	(0.216)	(0.041)	(0.005)	(0.181)
LEJ	0.074	0.009	-0.011	-0.068**	0.003	-0.114
	(0.046)	(0.079)	(0.135)	(0.025)	(0.003)	(0.113)
ZCZ	-0.138	0.202	-0.429	-0.138	0.019	-1.086**
	(0.155)	(0.262)	(0.449)	(0.084)	(0.01)	(0.377)
ES	-0.171	0.301	-1.933	0.302	0.021	-4.586
	(1.26)	(2.135)	(3.658)	(0.687)	(0.081)	(3.067)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant

Table D.11: VECM gamma coefficients for the April equities crash period

	Alpha	GFV -1	LEJ -1	ZCZ -1	ES -1	Dummy
GFV	-0.151*	-0.059	0.023	0.055	0.001	-0.19
	(0.074)	(0.102)	(0.151)	(0.063)	(0.002)	(0.227)
LEJ	0.067	0.119	-0.1503	0.037	-0.001	-0.239
	(0.052)	(0.072)	(0.106)	(0.044)	(0.002)	(0.159)
ZCZ	0.011	0.012	-0.069	-0.102	0.005*	-0.508*
	(0.073)	(0.102)	(0.15)	(0.063)	(0.002)	(0.225)
ES	4.413	-4.963	6.66	1.109	0.002	-18.28**
	(2.186)	(3.036)	(4.483)	(1.871)	(0.065)	(6.73)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant

Table D.12: VECM gamma coefficients for the April cattle crisis period

	Alpha	GFV -1	LEJ -1	ZCZ -1	ES -1	Dummy
GFV	-0.051*	-0.024	-0.034	0.057	-0.003	0.354*
	(0.024)	(0.061)	(0.092)	(0.032)	(0.002)	(0.15)
LEJ	0.015	0.197***	-0.271***	0.049*	-0.002	0.201*
	(0.016)	(0.04)	(0.061)	(0.021)	(0.001)	(0.099)
ZCZ	-0.001	0.117	-0.087	-0.062	0.001	-0.172
	(0.027)	(0.069)	(0.104)	(0.036)	(0.002)	(0.17)
ES	-0.392	-0.07	-1.945	1.446*	-0.022	18.684***
	(0.424)	(1.088)	(1.639)	(0.572)	(0.036)	(2.684)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant

Table D.13: VECM gamma coefficients for the December full sample, without ES futures

	Alpha	GFQ -1	LEZ -1	ZCU -1
Equation GFQ	-0.013** (0.004)	-0.182*** (0.025)	0.207*** (0.038)	0.002 (0.009)
Equation LEZ	-0.002 (0.003)	0.028 (0.016)	-0.068** (0.025)	0.005 (0.006)
Equation ZCU	-0.004 (0.006)	0.021 (0.037)	-0.012 (0.057)	-0.021 (0.013)
	GFQ -2	LEZ -2	ZCU -2	Dummy
Equation GFQ	-0.094*** (0.025)	0.0715 (0.038)	-0.013 (0.009)	-0.1** (0.037)
Equation LEZ	0.007 (0.016)	-0.041 (0.025)	-0.001 (0.006)	-0.136*** (0.025)
Equation ZCU	-0.036 (0.037)	0.081 (0.056)	-0.044*** (0.013)	-0.408*** (0.056)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.14: VECM gamma coefficients for the December pre-COVID-19 period, without ES futures

	Alpha	GFQ -1	LEZ -1	ZCU -1
Equation GFQ	-0.014 (0.007)	-0.138*** (0.034)	0.167** (0.058)	-0.03** (0.011)
Equation LEZ	0.003 (0.004)	0.091*** (0.02)	-0.215* (0.035)	-0.004 (0.006)
Equation ZCU	-0.045** (0.017)	0.112 (0.079)	0.008 (0.137)	-0.033* (0.025)
	GFQ -2	LEZ -2	ZCU -2	Dummy
Equation GFQ	-0.101** (0.034)	0.135* (0.058)	0.001 (0.011)	-0.036 (0.032)
Equation LEZ	-0.021 (0.02)	-0.003 (0.034)	0.002 (0.006)	-0.133*** (0.019)
Equation ZCU	0.108 (0.079)	-0.111 (0.136)	-0.001 (0.025)	-0.549*** (0.076)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.15: VECM gamma coefficients for the December equities crash period, without ES futures

	Alpha	GFQ -1	LEZ -1	ZCU -1	Dummy
Equation GFQ	-0.014 (0.007)	-0.138*** (0.034)	0.167** (0.058)	-0.03** (0.011)	-0.647*** (0.134)
Equation LEZ	0.003 (0.004)	0.091*** (0.02)	-0.215* (0.035)	-0.004 (0.006)	-0.537*** (0.089)
Equation ZCU	-0.045** (0.017)	0.112 (0.079)	0.008 (0.137)	-0.033* (0.025)	-0.656*** (0.149)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.16: VECM gamma coefficients for the December cattle crisis period, without ES futures

	Alpha	GFQ -1	LEZ -1	ZCU -1	Dummy
Equation GFQ	-0.0402** (0.013)	-0.0602 (0.057)	-0.013 (0.088)	0.026 (0.024)	0.277* (0.122)
Equation LEZ	-0.007 (0.009)	0.086* (0.038)	-0.149* (0.058)	0.017 (0.016)	0.184* (0.08)
Equation ZCU	-0.014 (0.015)	0.142* (0.068)	-0.214* (0.105)	-0.046 (0.028)	-0.45** (0.145)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.17: VECM gamma coefficients for the December return to normalcy period, without ES futures

	Alpha	GFQ -1	LEZ -1	ZCU -1
Equation GFQ	0.003 (0.006)	-0.1** (0.037)	0.005 (0.053)	0.002 (0.01)
Equation LEZ	0.01** (0.004)	0.095*** (0.025)	-0.213*** (0.037)	0.01(0.0067)
Equation ZCU	0.031** (0.012)	0.004 (0.079)	-0.094 (0.115)	0.048* (0.021)
	GFQ -2	LEZ -2	ZCU -2	Dummy
Equation GFQ	-0.085* (0.037)	0.12* (0.053)	-0.001 (0.01)	-0.141** (0.043)
Equation LEZ	-0.002 (0.026)	0.005 (0.037)	0.005 (0.007)	-0.164*** (0.03)
Equation ZCU	-0.093 (0.079)	0.079 (0.114)	-0.044* (0.021)	-0.09 (0.093)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.18: VECM gamma coefficients for the February full sample, without ES futures

	Alpha	GFQ -1	LEG -1	ZCU -1
Equation GFQ	-0.016** (0.005)	-0.155*** (0.026)	0.17*** (0.04)	0.001 (0.009)
Equation LEG	-0.002 (0.003)	0.063*** (0.017)	-0.127*** (0.026)	0.006 (0.006)
Equation ZCU	-0.005 (0.007)	0.009 (0.039)	0.0038 (0.06)	-0.022 (0.014)
	GFQ -2	LEZ -2	ZCU -2	Dummy
Equation GFQ	-0.099*** (0.026)	0.082* (0.04)	-0.01 (0.009)	-0.091* (0.041)
Equation LEG	0.013 (0.017)	-0.039 (0.026)	0.003 (0.006)	-0.123** (0.026)
Equation ZCU	-0.034 (0.038)	0.091 (0.06)	-0.039** (0.014)	-0.442** (0.06)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.19: VECM gamma coefficients for the February pre-COVID-19 period, without ES futures

	Alpha	GFQ -1	LEG -1	ZCU -1	Dummy
Equation GFQ	-0.017 (0.012)	-0.0444 (0.044)	0.042 (0.074)	-0.026 (0.015)	-0.028 (0.046)
Equation LEG	0.017* (0.007)	0.164*** (0.026)	-0.227*** (0.044)	0.006 (0.009)	-0.14*** (0.027)
Equation ZCU	-0.056* (0.028)	0.059 (0.1)	-0.052 (0.169)	-0.045 (0.033)	-0.645*** (0.104)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.20: VECM gamma coefficients for the February equities crash period, without ES futures

	Alpha	GFQ -1	LEG -1	ZCU -1	Dummy
Equation GFQ	-0.04 (0.031)	-0.212** (0.066)	0.408*** (0.101)	-0.037 (0.037)	-0.591*** (0.141)
Equation LEG	0.041 (0.021)	-0.004 (0.045)	0.054 (0.068)	-0.008 (0.025)	-0.457*** (0.095)
Equation ZCU	0.034 (0.035)	0.144 (0.073)	-0.046 (0.112)	-0.08 (0.041)	-0.594*** (0.156)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.21: VECM gamma coefficients for the February cattle crisis period, without ES futures

	Alpha	GFQ -1	LEG -1	ZCU -1	Dummy
Equation GFQ	-0.044**	-0.063	-0.005	0.017	0.274*
	(0.015)	(0.058)	(0.089)	(0.024)	(0.123)
Equation LEG	-0.003	0.077*	-0.149*	0.008	0.183*
	(0.01)	(0.038)	(0.058)	(0.016)	(0.081)
Equation ZCU	-0.018	0.085	-0.118	-0.04	-0.524***
	(0.018)	(0.068)	(0.105)	(0.029)	(0.146)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.22: VECM gamma coefficients for the February return to normalcy period, without ES futures

	Alpha	GFQ -1	LEG -1	ZCU -1
Equation GFQ	-0.008 (0.006)	-0.112** (0.037)	0.029 (0.058)	-0.001 (0.01)
Equation LEG	0.003 (0.004)	0.096*** (0.0232)	-0.241*** (0.037)	0.009 (0.006)
Equation ZCU	0.038** (0.014)	-0.094 (0.079)	0.082 (0.124)	0.041 (0.021)
	GFQ -2	LEG -2	ZCU -2	Dummy
Equation GFQ	-0.06 (0.037)	0.08 (0.057)	-0.001 (0.01)	-0.136** (0.043)
Equation LEG	0.032 (0.023)	-0.063 (0.037)	0.006 (0.006)	-0.134*** (0.027)
Equation ZCU	-0.043 (0.079)	-0.0224 (0.124)	-0.038 (0.021)	-0.083 (0.093)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.23: VECM gamma coefficients for the April full sample, without ES futures

	Alpha	GFV -1	LEJ -1	ZCZ -1
Equation GFV	-0.02** (0.007)	-0.178*** (0.03)	0.19*** (0.046)	0.007 (0.012)
Equation LEJ	0.002 (0.005)	0.132*** (0.02)	-0.226 (0.031)***	0.0144 (0.008).
Equation ZCZ	0.002 (0.01)	0.039 (0.043)	-0.046 (0.065)	-0.02 (0.017)
	GFV -2	LEJ -2	ZCZ -2	Dummy
Equation GFV	-0.182*** (0.03)	0.244*** (0.045)	-0.023 (0.012)	-0.092 (0.055)
Equation LEJ	-0.038 (0.02)	0.057 (0.03)	-0.01 (0.008)	-0.12** (0.037)
Equation ZCZ	-0.057 (0.043)	0.055 (0.064)	-0.004 (0.017)	-0.366*** (0.078)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.24: VECM gamma coefficients for the April pre-COVID-19 period, without ES futures

	Alpha	GFV -1	LEJ -1	ZCZ -1	Dummy
Equation GFV	-0.12 (0.069)	-0.055 (0.125)	-0.033 (0.215)	-0.065 (0.04)	-0.053 (0.18)
Equation LEJ	0.059 (0.043)	0.015 (0.078)	-0.02 (0.134)	-0.065** (0.025)	-0.112 (0.113)
Equation ZCZ	-0.187 (0.145)	0.216 (0.263)	-0.453 (0.45)	-0.105 (0.083)	-1.062** (0.379)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.25: VECM gamma coefficients for the April equities crash period, without ES futures

	Alpha	GFV -1	LEJ -1	ZCZ -1	Dummy
Equation GFV	-0.058 (0.056)	-0.101 (0.099)	0.103 (0.146)	0.047 (0.059)	-0.205 (0.226)
Equation LEJ	0.072 (0.039)	0.117 (0.069)	-0.158 (0.101)	0.031 (0.041)	-0.243 (0.157)
Equation ZCZ	-0.008 (0.056)	0.056 (0.099)	-0.043 (0.146)	-0.051 (0.059)	-0.553* (0.225)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

Table D.26: VECM gamma coefficients for the April cattle crisis period, without ES futures

	Alpha	GFV -1	LEJ -1	ZCZ -1	Dummy
Equation GFV	-0.044** (0.015)	-0.063 (0.058)	-0.005 (0.089)	0.017 (0.024)	0.274* (0.123)
Equation LEJ	-0.003 (0.01)	0.077* (0.038)	-0.149* (0.058)	0.008 (0.016)	0.183* (0.081)
Equation ZCZ	-0.018 (0.018)	0.085 (0.068)	-0.118 (0.105)	-0.04 (0.029)	-0.524*** (0.146)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level

Table D.27: VECM gamma coefficients for the April return to normalcy period, without ES futures

	Alpha	GFV -1	LEJ -1	ZCZ -1
Equation GFV	-0.033 (0.023)	-0.115 (0.063)	0.105 (0.097)	0.046 (0.031)
Equation LEJ	0.024 (0.015)	0.166*** (0.042)	-0.234*** (0.065)	0.037 (0.02)
Equation ZCZ	0.004 (0.026)	0.088 (0.072)	-0.034 (0.11)	-0.053 (0.035)
	GFV -2	LEJ -2	ZCZ -2	Dummy
Equation GFV	-0.243*** (0.063)	0.287** (0.094)	-0.058 (0.031)	0.385* (0.15)
Equation LEJ	-0.055 (0.042)	0.094 (0.063)	-0.02 (0.02)	0.211* (0.1)
Equation ZCZ	-0.114 (0.071)	0.094 (0.107)	0.04 (0.035)	-0.158 (0.17)

Note: Null = γ is not significant; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level.

APPENDIX E. COMPARISON BETWEEN ES FUTURES, NEARBY LIVE AND DEFERRED CATTLE FUTURES

To accurately model time lags in cattle finishing the spreads were composed of deferred futures contracts as opposed to nearby ones. These deferred contracts were not the nearest contracts to the equities crash or plant shutdowns that the study focuses on. To check for any discrepancies between the nearby and deferred futures contracts, the same analysis used for ES futures and the crush spreads is ran on the April 2020 live cattle contract and the same rolling ES futures that was used in the rest of this research.

The spreads were designed around the live cattle contracts as that is where the crush spread ends with cattle heading to be slaughtered. The nearest spread to these events is the December spread which include the August feeder cattle contract, the September corn contract, and the December live cattle contract. There are four live cattle contracts that come before the December contract: April, June, August, and October. Each of these contracts was left out of the final research because either the contract itself expired prior to the end of the study period or the feeder cattle contract that would've preceded the live cattle contract by four to six months expired too soon.

Bivariate analysis between the rolling ES futures and the April 2020 live cattle contract (LEJ20) was performed to observe how the nearby futures behaved when compared to the deferred contracts. The live cattle contract was chosen for these tests as opposed to feeder cattle contracts as it has more daily volume, is physically settled and live cattle's end destination are slaughter facilities which were famously impacted by the virus. The same cointegration tests that were employed in the core of this research were again used to compare the ES contract and LEJ20 as well as LEJ20 and the other deferred live cattle contracts in the study.

The relationship between nearby and future prices of commodities is a fundamental item of study in agricultural economics. One of the earlier theories around the relationship between nearby and deferred storable commodity futures contracts hypothesized that their relationship was determined by the storage cost of the commodity (Working , 1949). Under this paradigm, nearby contracts are where most price discovery occurs, and deferred contracts adjust to moves in the nearby based on storage costs. Recent empirical research finds that most price discovery for agricultural futures occur in the nearby contract but begin to shift out towards the deferred contracts as expiration approaches (Schnake et al, 2012). A study examining price discovery among nearby and deferred contracts in corn and live cattle futures markets found that nearby contracts were less determinant for live cattle futures than corn futures. The authors attributed this to the difference in storability between corn, which is storable, and live cattle, which is nonstorable (Hu et al, 2020).

Figure E.1 is a graph of LEJ20 alongside the other live cattle contracts in the study from January 1st, 2020, to April 30th, 2020, the last day of trading for LEJ20. The movements of LEJ20, designated by green line, mimic the other deferred contracts quite closely. Aside from the graph, cointegration tests on LEJ20 and the rolling ES contract and LEJ20 with the other live cattle contracts are performed. Cointegration test results for the ES and LEJ20 futures are in table E.1. These tests reveal that ES futures and LEJ20 futures are cointegrated to the 10% level during the equities crash period of the study. Futures for ES and LEJ20 are not cointegrated over the full sample nor during any of the other sub periods. The cointegration in the equities crash period is a lower level of cointegration than seen among the three spreads, but they are all also cointegrated to at least the 10% during the equities crash period.

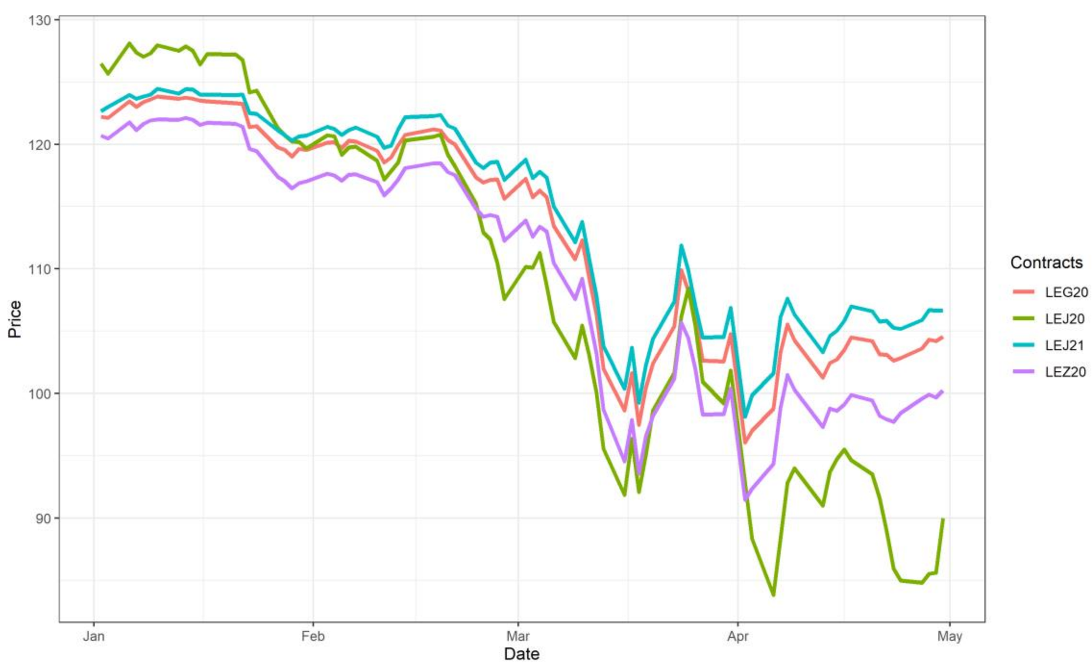

Figure E.1: Graph of nearby live cattle contract, LEJ20, and the deferred futures in the study

Note: This graph shows the three live cattle futures from the full research and the nearest live cattle contract to the equities crash, April 2020 (LEJ2020) in green.

Cointegration analysis was performed on LEJ20 and the other live cattle contracts. These results find that both during the full sample period of January to the end of April as well as during all the subperiods (excluding post April as the LEJ20 contract expires 4/30/2020) the live cattle contracts are cointegrated to the 1% level. These results are also in table E.1 below. In my view, these findings provide strong backing for the use of deferred contracts as opposed to nearby contracts in this study.

Table E.1: Results from cointegration tests on April 2020 live cattle futures and the E-Mini S&P 500 futures contract

Futures	Full Sample	Pre-COVID-19	Equity Crash	Cattle Crisis	Return to Normalcy
April 2020 live cattle (LEJ2020) and ES futures			*		
LEJ20 on the deferred LE contracts in the study	***	***	***	***	

Note: Null = series is not cointegrated; * - Significant at the 10% level; ** - Significant at the 5% level; *** - Significant at the 1% level. Subperiod definitions: Pre-COVID-19, 1/01/2020-2/23/2020; Equity Crash, 2/24/2020-3/18/2020; Cattle Crisis, 3/19/2020-4/29/2020; Return to Normalcy, 4/30/2020-7/01/2020*. No return to normalcy tests are run with the April 2020 live cattle futures as it expires on April 30th.

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