How has price discovery in the beef complex changed over time?

by

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Abstract

The negotiated cash market for live cattle has experienced significant reduction in volume and regional representativeness over the past few decades as a shift towards alternative marketing methods has occurred. It is important to understand how this shift may have changed the cash market's role in price discovery and relationship to other related markets such as the live cattle futures or boxed beef markets. Determining each market's role in price discovery and interaction amongst the other markets is valuable in assessing whether the current markets provide sufficient and accurate pricing information for fed cattle. In this study, weekly price series data from January 2002 through July 2019 is used to determine the relationship between the negotiated cash live cattle market, the live cattle futures market, and the boxed beef market. The study also assesses whether a shift has occurred in this relationship, and if so, when that shift occurs. Findings indicate that the live cattle futures market is dominant in price discovery and that more research would likely be necessary to better understand boxed beef's relationship to both the cash and futures markets.

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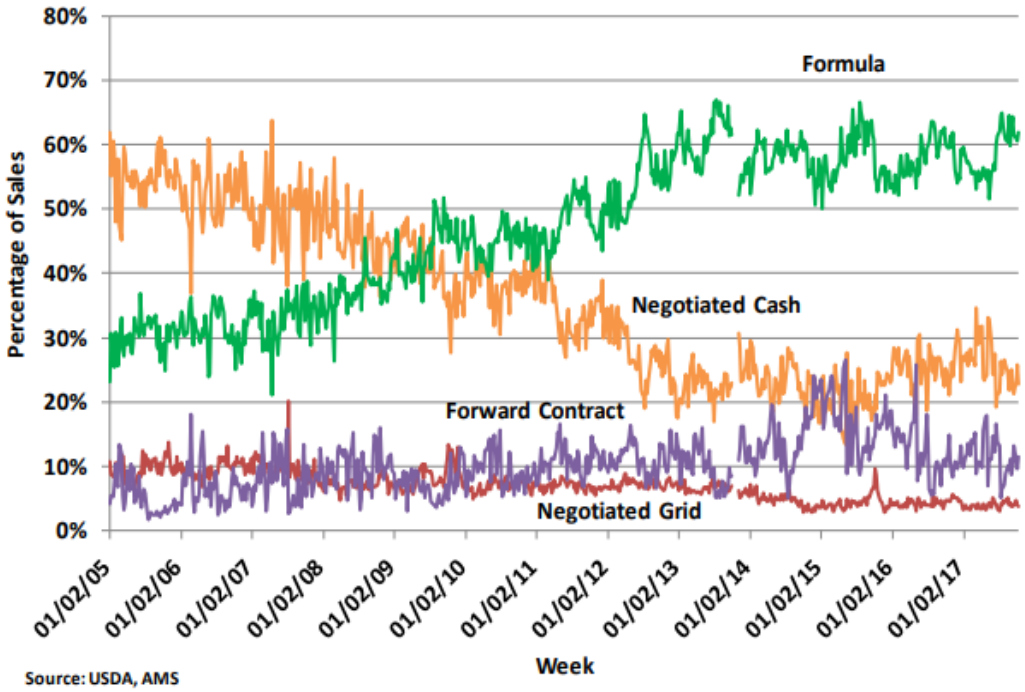
Introduction

Over the last few decades, there has been a large shift in the ways fed cattle are marketed which has caused concern regarding price discovery in the industry. Increased concentration of large feedyards and vertical alliances within the supply chain have led to alternative marketing methods to traditional cash negotiated trade being used more often. Without sufficient trade volume in the cash market, associated market information may be unreliable, which would be concerning for price discovery in the industry. The once predominant negotiated cash trade has shifted from representing about 60% of trade volume 15 years ago to now often below 30% of the total market trading, as can be seen in **Figure 1** (USDA AMS).

Thinness in negotiated cash markets results in substantial challenges for USDA market price reporting especially relative to data confidentiality concerns, reduces the reliability and

Figure 1: Shares of Methods Used to Market Fed Cattle Nationally, Weekly 2005-2019



representativeness of marketing information that is reportable and reported, and generally raises

questions about overall price discovery efficiency in both the live cattle futures and cash cattle markets.

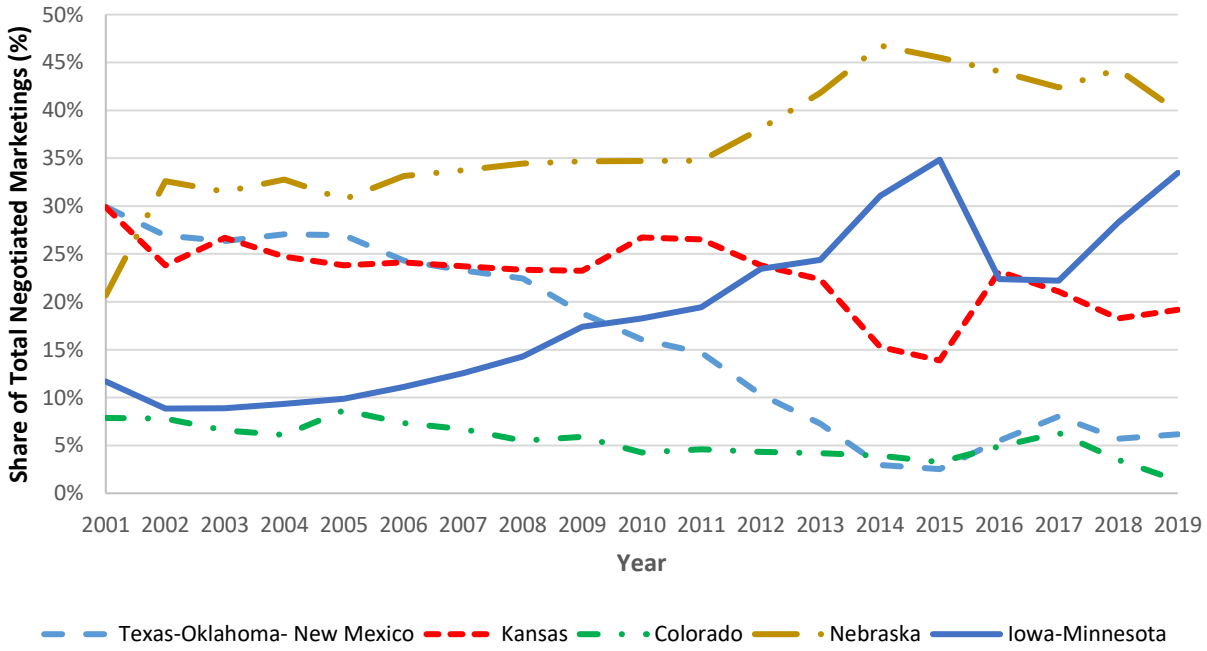
The trend away from negotiated cash markets to alternative marketing methods has continued throughout recent years, which has likely forced some adaptation in price discovery. The relationship between the negotiated cash market and live cattle futures market has been the focus of past research evaluating each market's role in price discovery using standard time series econometric methods. Past studies have varied results depending on the time period studied, the geographical data used, and methods and research techniques. One consistent result has been price discovery feedback between both cash negotiated fed cattle and the live cattle futures markets.

This study builds on previous research by providing an updated evaluation on the fed cattle cash and futures markets and their roles in price discovery since the market structure has shifted. If these roles have changed, there may be increased reliance on downstream markets, such as boxed beef, for price discovery in the cattle industry. The majority of past studies took place before 2014 or are based on data from 2014 and earlier. Large shifts away from negotiated cash to formula purchases have mostly occurred since 2014. At the time of those studies there would not have been a significant amount of data from after the movement to fully demonstrate whether there has been a change in the roles of price discovery after the markets adjusted to the thinness. Aside from the market structural change, significant events have happened since these studies and it is important to examine the markets after these. An example is a processing plant in Plainville, TX closed in 2013 which caused a large shock in the cattle and boxed beef markets. There have also been some major disruption in more recent months that have been omitted from this study due to lack of data points after the events that would allow for adjustments to occur,

but would be important to look at in the future. There was a fire at a processing plant in Holcomb, Kansas in August of 2019, causing prices of cattle to fall and boxed beef prices to rise as there were more cattle than there was carrying capacity at plants. In 2020 there has been the emergence of the global pandemic caused by COVID-19, which has likely caused enough disruption to be the sole focus of many future studies.

Another important thing to note about the time period that these previous studies took place in is that not only were there more cash trades previously; the trades were also more geographically representative of the overall market. Since then, reported negotiated cash market information in general has been more sparse, with much smaller volumes of cattle. A key issue with this decrease in volume is that the decrease has not been consistent among the five regions. **Figure 2** illustrates the disproportionate changes in market representativeness over time for the regions. The Nebraska and Iowa-Minnesota regions represent an increasing and dominant share

Figure 2: Annual Average Share of Weekly Total Cash Negotiated Steer and Heifer Volume for the Five Market Region, 2001-2019



Source: Calculated from USDA-AMS data

of cattle sold in the negotiated cash market, representing as much as 83% (in 2015) of the volume of fed cattle sold in the cash market. On the other hand, the share of Texas-Oklahoma-New Mexico in the negotiated cash market has significantly decreased to representing less than 10% of the total volume since 2012.

The problem with the varied representation of the regions in the negotiated cash market is that the share of negotiated trade does not coincide with the share of fed cattle produced and sold in each region. For example, in 2017 the Texas-Oklahoma-New Mexico region led the US in fed cattle marketed with 26% of total cattle sold, but only made up about 8% of cattle sold in the negotiated cash market, the second lowest of the five major market areas. In contrast, the Iowa-Minnesota region held the smallest share of total US cattle marketed of the major market areas (7%) yet represented the second largest share in the negotiated cash market (Schroeder, Tonsor, and Coffey 2018). Furthering the issue of representativeness is that although past studies (Pendell and Schroeder 2006, Wright 2017) have found that the prices of fed cattle in the five regions are cointegrated with each other, there can be significant differences in prices between regions. When there are price differences amongst the regions, the weighted-average of reported negotiated cash prices will be skewed towards the Nebraska and Iowa-Minnesota regions, which may not accurately represent current supply and demand fundamentals present in the other regions or the US fed cattle market as a whole.

Given the dramatic change in the nature of negotiated fed cattle market information, there is considerable interest in determining whether the feedback of price discovery between negotiated cash and futures markets persists and if not, whether futures price discovery is more dominant or relying more on downstream market information, such as wholesale boxed beef markets. The objective of this study is to test whether price discovery in fed cattle cash and

futures markets has shifted with the thinning cash market and whether downstream market prices (e.g., boxed beef) are becoming more important in price discovery in the cattle industry.

To do this, weekly price data from 2002 through July 2019 for live cattle futures, boxed beef, and negotiated cash markets is used. Many previous studies also utilized weekly reports, but most of those studies took place before the cash markets were as thin as what we see today. This study compares the futures price series to the negotiated cash markets, and to the boxed beef market. The negotiated cash market numbers used are a combination of live and dressed cattle from the entire 5-region market of all steers and heifers, as opposed to looking at each regional market individually. The changes in prices over time for all three prices series can be seen in **Figure 3**. In looking at the model of the three series, it clear that there is a relationship between the price series as they move together over time. The question that is being examined is what that relationship between the series is, and whether it has changed over time. This will be done using cointegration tests, a Vector Error Correction Model, and price discovery techniques.

In order to do the cointegration tests, stationarity is tested using the Augmented Dickey Fuller test. If the price series have the same unit root, then cointegration methods are utilized employing the Johansen test, the Engel Granger method and error correction models. These are all common approaches of past research in live cattle as well as other commodities. The Gregory Hansen test is also used to explore possible changes in structure, or a regime shift, of the markets. This test is applied to the negotiated cash market relationship with the futures and boxed beef prices to see whether there was a change in structure between the markets over time, and if so, when that change occurred and its impact. The potential change in structure is used to perform a study of price leadership roles using the entire data price series compared to price leadership roles after a break or change of structure occurred. Price series relationships are

tested between the negotiated cash and live cattle futures markets, the boxed beef and live cattle futures market, and the negotiated cash and boxed beef markets.

Literature Review

Price discovery relating to livestock markets, particularly fed cattle and hog markets, is not a new topic of study and has been examined a lot over the past few decades as the markets have changed. To understand the relationships within the cattle market and see how they may have changed over time, it is important to review the past studies and build off of those.

Cattle Market Structure

Over the past few decades, the market structure of fed cattle has significantly changed and evolved from being predominantly traded using cash negotiations to using alternative methods such as forward contracts, negotiated grid pricing, or formula pricing.

Cattle sold in the negotiated cash market, or the spot market, are under current USDA-AMS definitions scheduled to be delivered to the packing plant within 30 days of the agreement and the price is determined through buyer and seller interaction. Even within the cash market there are variations in how cattle are sold. Cattle can either be sold "live" which means prices are on a live weight basis or they can be "dressed" which means that prices are based on a dressed (carcass) weight. The prices can also include delivery, meaning the seller covers the delivery fee, or they can be sold 'Free on Board' (FOB) meaning the buyer covers the freight costs, which are dependent on the distance traveled. There is also variation in the prices for cattle sold live FOB because the shrink of the animals is accounted for at the time of the sale. This means that the cattle are weighed at the feedyard and an agreed upon pencil shrink is subtracted from the weight to get the actual transactional weight used in the sale. The amount of pencil shrink varies by region and is an estimate, so it could be a larger or smaller deduction of weight compared to what actually occurs. This is not a consideration in cattle sold with delivery

because the cattle are weighed after slaughter at the delivery location, so no shrink needs to be accounted for. The vast majority of negotiated fed cattle volume is consistently sold either as Live FOB or Dressed Delivered, so that is the cash market data included in this study.

Forward contracts are a way to sell cattle further in advance of their delivery to the plants. Prices for forward contracts are typically established by using a base price from the CME live cattle futures markets or what is often referred to as a basis contract. Negotiated grid marketed cattle are typically sold/purchased within two weeks of the expected delivery to the plant with a base price that is negotiated by the buyers and sellers. The base price is determined at the time of the agreement or sale, but a final net price is not known until after slaughter because a series of premiums and discounts are applied based on carcass performance. Cattle sold by methods other than negotiated cash, forward contracts, or grid are considered to be sold using formula pricing. In formula purchases, the price is usually not known at the time of the agreement but is based on a formula that uses other market information, such as the futures or the cash market, as a base price (USDA AMS).

The use of alternative marketing method poses a few possible issues. Since formula pricing is based on the available existing marketing information, it does not aid in price discovery. Although formula pricing does not always directly use the negotiated cash market as the base price, the negotiated cash market is related to any method or market that may be used. This is important because while weekly negotiated cash prices only represent 10-30% of the fed cattle sold, it helps with price discovery for another 55-65% of cattle (Schroeder, Tonsor, and Coffey 2018). This makes it imperative that the cash market provides accurate and representative information for price discovery.

Market Thinness

The concern throughout the cattle industry over the past few decades is that there are not enough cattle transactions reported to provide the information needed to assess fair, or accurate, market prices. Studies dating back to at least 20 years ago (e.g., Schroeder and Mintert 2000), express valid concerns of decreasing volume of cattle marketed under negotiated cash, and since then volume has declined notably. In 2005 about 50-60% of cattle were marketed through negotiated purchases compared to only 20-30% by 2013. The decline in transactions brings about many concerns around the representativeness of these prices, which could bring distortions to the industry as a whole (Coffey, Tonsor, and Schroeder 2018).

The volume of fed cattle in cash negotiated trade has not only varied immensely through time – it also has varied regionally. There are five major marketing regions that cattle are reported under by USDA in the United States – Nebraska (NE), Kansas (KS), Iowa-Minnesota (IA/MN), Texas-Oklahoma-New Mexico (TX), and Colorado (CO). Out of these regions, Nebraska has the largest share of cattle negotiated under cash markets, representing about half of the transactions. In contrast, Texas-Oklahoma-New Mexico and Colorado each comprise of 10% or less of the total volume reported. KS and IA/MN make up the rest at about 20%-30% of the negotiated transactions each (Schroeder and Coffey 2019). This means that the weighted-average of the negotiated cash market is dominated by the Nebraska, Kansas and Iowa/Minnesota regions, which is not necessarily an accurate representation of the southern plains markets, which are responsible for a much larger share of total live cattle that are produced (Schroeder, Tonsor, and Coffey 2018).

Part of the issue in getting significant volumes of cattle reported in each region regularly is confidentiality concerns. If there are not enough firms reporting data and transactions being

reported, then confidentiality for the firms that do report data is lost. Breaking up the data by region contributes to the loss of volume due to confidentiality concerns because if there are not enough cattle traded that day/week to ensure confidentiality, then those sold will not be reported. An additional way to break up the reported data would be to break it up by the delivery window at the time of the transactions. This would mean creating a window for purchases scheduled to deliver 0-14 days and 15-30 days from the time of the negotiation. This is an important distinction because averaging over the entire 30-day time period causes the numbers to be averaged and aggregated which could hide market trends. Schroeder, Schulz, and Tonsor (2019) examine the feasibility of using separate delivery window categories for fed cattle. Their findings indicate that as the market currently is, most regions do not have the volume in reports to cover both windows and consistently report data with confidentiality intact. One solution that could help this issue would be to realign the regions so that the transactions are balanced, because in some states or regions, one delivery window may be more common than the other. This solution relies on the states within the realigned regions following the same market trends because otherwise aggregating data in these regions would not reveal accurate trends. Even without attempting to create separate delivery windows, the Texas/Oklahoma/New Mexico region data is so low in volume and inconsistent with reportability that USDA may need to either combine the data with another state, such as Kansas (which could reduce quality of data) or be discontinued in the negotiated cash report (Schroeder, Schulz, and Tonsor 2019).

Aside from concerns about regional representation of the cash negotiated market information, there is also a potential problem with the quality representation from these negotiations. Beef product differentiation is having an increasingly large impact on the industry with producers using USDA's Producer Verified Programs and other value-enhancements to sell

their cattle at a premium. In some situations, cattle can be sold on a quality grade grid which means that producers would receive higher prices for cattle that have a higher percentage of Choice and higher quality grade. Cattle produced and marketed under these programs would not be included in the negotiated cash markets as producers would not get the same premiums in the negotiated cash market, so cattle of higher quality may not be fully represented in the cash negotiated market, but their prices could still be dependent on the cash market using formula pricing to adjust for quality.

Boxed Beef

The boxed beef market is considered a spot market that comprises negotiated sales that are fulfilled within 21 days of an agreement. These sales are between packers and their customers (processors, grocers, restaurants, food distribution companies, etc.) at the wholesale level for beef that is packaged in 40 to 60-lb boxes. The reported prices are an average of these negotiated sales and are quoted at the price per 100-pound scale. Prices are calculated and reported daily for unbranded, Choice and Select grade beef. These prices are reported by the USDA, which allows market participants to use them to help determine buying and selling prices, as well as compare their performance and sales prices relative to the rest of the industry. Boxed beef prices are considered a reliable source of information on price levels and trends for the next level in the cattle marketing chain, but have historically not been given as much attention when it comes to price discovery in the fed cattle market (Joseph 2016).

There are a few ideas from past research that may help explain why using a reliable downstream market to inform the upstream market could be less reliable. Schroeder and Mintert (2000) found that the difference in fed cattle and boxed beef prices could be largely dependent on processing margins, which could drastically change over time. Another important factor is

that the markets could have significantly different temporal aspects. Throughout a year, the demand for boxed beef changes with the seasons and upcoming events, and these changes do not necessarily reflect the changes of supply of cattle further up the market. Even within the boxed beef markets there are demand shifts that impact the prices of Choice and Select grade beef differently. An example of this is that around the Christmas season every year, the demand for Choice meats increases, leading to an increase in the Choice premium relative to Select meats (USDA AMS).

Livestock Mandatory Reporting

One effort that was made to increase the price transparency and market information with livestock markets was the Livestock Mandatory Reporting Act which was passed by Congress and implemented in April of 2001(Pendell and Schroeder 2006). This Act was created to implement a mandatory system for price reporting in livestock and meat products in order to address concerns about representativeness and availability of market information. To do this, LMR required that transaction prices and volume be reported by qualifying packers. This includes transactions of buying fed cattle and the sale of beef products to get the boxed beef prices. The transaction information is reported to USDA AMS where it is then compiled and publicly reported daily. Despite the declining cash market, LMR is considered a success in increasing the volume and representativeness of trade and has remained in place.

While LMR has been valuable in providing information that can help track structural changes within markets, it is far from a perfect solution. Since LMR has been in place, it has been difficult to find voluntary price reporting and regional market reports that used to be regularly reported. Another issue is that not all reported prices are able to be published to the public due to confidentiality concerns. As a general rule, price information cannot be reported if

it represents less than three firms and if one firm is providing 70% or more of the data for a given reporting period. Many studies have been done since the LMR act was put in place to test its effectiveness and change in the markets. In a study by Pendell and Schroeder (2006) the impact of LMR on spatial market integration was explored. Cointegration was found between the regional markets both before and after LMR, but after implementation integration of price series between regions strengthened in most cases, indicating that price information was being communicated more effectively.

Price Discovery

The term price discovery refers to interactions and relationships between various markets, how information is being transmitted between markets, and to what degree markets are integrated with each other (Coffey, Pendell, Tonsor 2019). Price discovery refers to the use of one market in determining the prices of another market. If one market has a large share in price discovery, then fluctuations of that dominant market would be reflected in related markets.

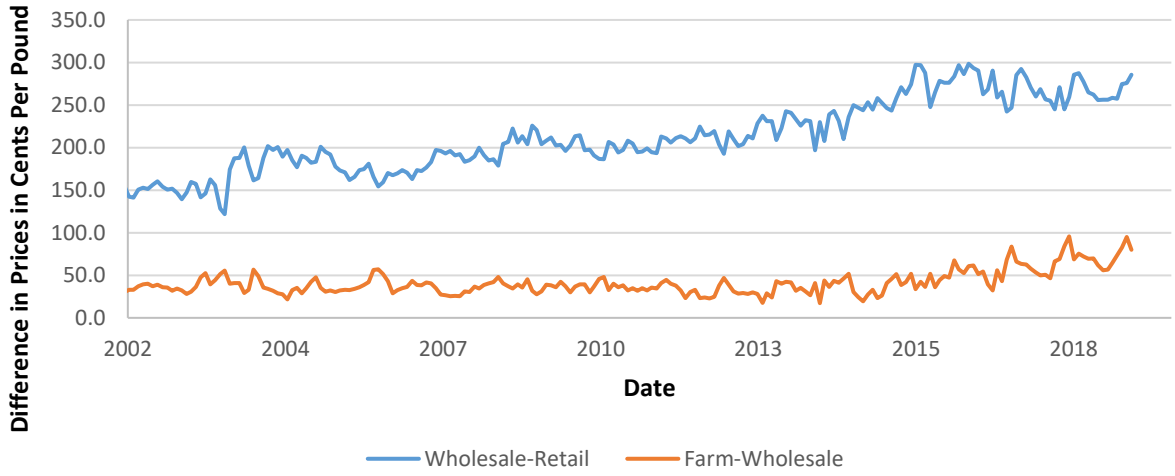
The focus of a lot of studies around price discovery within the cattle market has been to look at price discovery in the cash markets between different regions. Overall, studies consistently find regional markets to be cointegrated (Bailey and Brorsen, 1989; Schroeder and Goodwin, 1990; Pendell and Schroeder, 2006), with larger volume markets being more dominant and price adjustments occurring between regions within a few weeks if a market shock occurs.

With the decline in reporting within the cash markets for fed cattle, there has been a lot of research around other methods of price discovery using alternative markets, such as the live cattle futures or boxed beef markets. Schroeder and Mintert examined alternative markets to use in price discovery in 2000 by using futures and boxed beef price series. They found both

markets viable references for cash negotiations but noted limitations within both. Limitations within the futures market are that the timing of purchases for futures does not necessarily match live trades, the large amount of variability that can occur with the basis, and that a strong cash market is necessary for the futures prices to be reliable. That being said, the CME live cattle contracts could be physically fulfilled or delivered on if positions are not offset by the expiration of the contract, so that should cause the cash and futures markets to converge. The physical delivery to fulfill a contract is rare and can be a difficult process with determining delivery specifications and other details, which has brought the effectiveness of physical delivery of the CME contracts into question (Schroeder and Coffey 2018)

Using downstream products such as boxed beef as an alternative market has shown mixed results relative to its role in price discovery in previous studies. Some of the problems with using boxed beef prices are issues around a large amount of variation in relationships over time. The fluctuation of the difference between boxed beef and cattle prices can be caused by many factors (changes in slaughter, processing, marketing prices, etc.) which makes it difficult to identify what causes changes and quantify how it will impact other markets such as fed cattle. **Figure 4** shows the price spread between beef at the farm level and beef at the retail level. It is broken up into two sections, farm to wholesale and wholesale to retail prices. From this figure, it is clear that there is some variation in the price spread over time, particularly between the wholesale and retail level. The more important spread to look at in this graph, however, is the spread between farm and wholesale since boxed beef is sold at a wholesale level. While this spread shows less variation, there is still a lot of movement in the price differences, particularly over the past 5 years. Further examining the price spreads, **Table 1** shows the descriptive statistics of the price spread.

Figure 4: Monthly Price Spread Between Beef at the Farm and Wholesale and Wholesale and Retail Level, 2002-July 2019



Source: USDA- ERS data

This table further confirms the story that the graph tells, with the wholesale to retail difference being consistently larger, with a range in the spread of $1.77 per pound over the time period. The farm-wholesale spread does not change as much, but still shows a spread of $0.78 per pound throughout the time period.

Table 1: Descriptive Statistics of Monthly Price Spread Between Beef Sold at Farm, Wholesale and Retail Level (2001-2019)

Descriptive Statistics	Farm-wholesale ($/cwt)	Wholesale-retail ($/cwt)
Mean	41.39	213.87
Median	38.27	206.03
Standard Deviation	14.08	41.21
Range	78.46	176.67
Minimum	17.26	121.83
Maximum	95.72	298.5

Source: USDA- ERS data

The reasoning for the variations in price spread is difficult to determine because the reason could be different from month to month. Events that cause large spikes in demand or significant drops in supply could happen at either a farm, wholesale, or retail level and the price shock from these events does not necessarily transfer through each market. This is because factors that affect the margins or derived supply and demand curves include marketing, processing and distribution costs which vary at every level of production, processing, and marketing. **Figure 4** does indicate an increasing gap between the farm-wholesale and wholesale-retail price spreads over time. This trend is expected as retail products have been adapted over time to become more consumer friendly. This movement increases processing and packaging costs but does not impact the cattle feeding costs.

The relationship between the Chicago Mercantile Exchange (CME) Live Cattle (LC) futures market and the negotiated cash market has been examined many times to find that these two markets are closely related. It is important when evaluating the relationship between the two markets to also identify which market is leading price discovery. If the futures market is the leading market, then increasing thinness in the cash markets is not quite as big of an issue in accurate price discovery. However, if the cash market is an integral part of price discovery and, then the thin cash markets become a bigger issue. Past studies on this relationship have come back with mixed results depending on methods used and the time period studied and are summarized in **Table 2**. Studies done by Oellermann, Brorsen and Farris (1989) used the Granger Causality test and found that futures prices of cattle explained cash prices but not the reverse, although they did find evidence of feedback between the two during some time periods.

Table 2: Summary of past research on price discovery between cash and futures for live cattle

Authors (publication year)	Study Years	Data Frequency	Methods	Cattle Price Discovery Leadership
Oellermann and Farris (1985)	1966-1972 1973-1977 1978-1982	Daily	Granger Causality	Futures led cash Futures led cash Feedback
Bessler and Covey (1991)	1985-1986	Daily	Cointegration	Nearby futures & cash cointegrated
Koontz et al. (1990)	1973-1979 1977-1980 1981-1984	Weekly	Granger Causality	Feedback Cash led futures &mixed feedback Cash led futures & mixed feedback
Perry et al. (2005)	1998-2005	Weekly	Econometric Test	Cash price improved futures prediction
Matthews et al. (2015)	1990-2001 2002-2008 2008-2014 1990-2001 2002-2008 2008-2014	Weekly	Error Correction & Granger Causality Granger Causality	Futures dominated price discovery Futures with small feedback from cash Futures with small feedback from cash Feedback Cash led futures Cash led futures
Joseph, Garcia, Peterson (2013)*	2001-2012	Weekly	Econometric Test	Futures led cash & feedback

Source: Schroeder, Tonsor and Coffey (2018) with modifications/additions indicated by *

Koontz et al. (1990) also used the Granger test over a similar time period and found feedback between the two or that cash actually led futures. A more recent study by Joseph, Garcia and Peterson (2013) using the Granger test and an Error Correction Model (ECM) examined cash and futures markets, as well as boxed beef and found a cointegrated relationship between the three, with the futures largely leading cash and boxed beef markets, and the cash fed market dominated the boxed beef market.

Even with mixed results, it can be concluded that the markets are related and both markets need reliable information in order to allow for efficient price discovery. While previous studies have also looked at boxed beef and found little evidence of it having a significant role in price discovery, with the changing of market structure and possible lack of information from the negotiated cash market, boxed beef could have an increasing role.

Data

This study uses weekly cattle price data from January 2002 through July 2019. The cattle cash, futures and boxed beef prices are all from the Livestock Marketing Information Center (LMIC) comprised of the USDA-AMS LMR and CME Group data. The negotiated cash data comes from both FOB and Dressed/Delivered negotiated trade prices within a region. The regions studied include Texas/Oklahoma/New Mexico, Nebraska, Colorado, and Kansas, Iowa/Minnesota. Since previous studies have found cash negotiated prices in these regions to be cointegrated, they are combined to get one aggregated negotiated cash price series.

The decision to use weekly price series data was made in an attempt to get a sufficient amount of data points to accurately reflect the movement of the markets, as monthly, quarterly or annual data would be too aggregated to show the true changes over time. While daily data may be more ideal as it would provide more data points and follow the changes more closely, there are not enough fed cattle negotiated cash transactions to get fully representative data. There is a large amount of volume variations day to day and on many days at least one region will not have any reported data. The weekly data should be sufficient in discovering trends and determining

Table 3: Summary Statistics of Volume of Cattle Sold Weekly in Negotiated Cash Market, 2001-2019

Category	Weekly Average Volume (Hd)	Standard Deviation	Minimum	Maximum
Live Steer	42,016	18,209	2,479	129,272
Dressed Steer	24,098	11,054	102	74,720
Live Heifer	30,971	16,269	2,043	129,778
Dressed Heifer	15,509	8,926	786	79,397

Notes: *This table uses USDA LMR Cattle Price reports and shows the average weekly volume of cattle sold in the negotiated cash market separated by steers and heifers and cattle sold on an FOB basis (Live) and Dressed Delivered basis (Dressed).*

*This table excludes the weeks with no reported transactions. N=917 for all variables.

relationships over time, while also having enough transactions to accurately reflect the cash market.

The weekly average negotiated cash prices and volume comes from a weighted average from steer and heifer prices. The FOB and Dressed/Delivered prices are combined using a method that was outlined by Schroeder and Pendell (2016). With the thinness of the market and lack of volume in the negotiated cash market, this method allows both the live and d3333ressed data to be used, which helps to give more volume and accuracy within the data. As **Table 3** shows, by combining the data the volume of cattle being traded in the negotiated cash market is much higher than the volume would be if only the live or dressed/delivered data were being used.

The method that is being used converts the dressed prices to live prices and then takes the weighted average price between live and converted dressed prices. To do this, the five regions are combined to get a national weighted average price for each week for live steers, live heifers, dressed steers and dressed heifers. From there, the average dressed weight for steers and heifers is divided by the average live weight and then multiplied by the respective reported dressed prices. Live weight transportation costs were estimated at $0.50/cwt, which was subtracted from the dressed price to get a live price for both steers and heifers. Converted dressed prices are then combined with live prices to get a weighted average for both steers and heifers. To get this weighted average, the head of live cattle is multiplied by the live price and the head of dressed cattle is multiplied by the converted dressed price and these calculations are added together and then divided by the total head of cattle. The final step is to combine the steer and heifer price series again using a weighted average method.

The boxed beef prices are also taken as weekly weighted averages. The prices are a weighted average between Choice and Select using contract specifications outlined by the CME contracts. The specified weight between Select and Choice changed over time, starting at 55% Choice and 45% Select for most of the time period, before changing to 60% Choice and 40% Select in October 2017, and then changing again in October of 2018 to be 65% Choice and 35% Select. With this method, prices may naturally increase in later years due to different contract specifications that require higher quality in the contract. The boxed beef price series uses these contract specification weights to consistently account for the Select and Choice prices at a weighted average that is representative of the quality expectation of the cattle marketed.

The futures price series comes from LMIC as well and is created by using the nearby month price and the weekly average for that price. There is 3 weeks of missing data for boxed beef and negotiated cash markets due to a government shutdown where no trading happened in October of 2013, and a few other missing data points throughout. The numbers for these series with missing data points are filled in using linear interpolation.

Although this study takes place in 2020, the data used is only through July 2019 due to unprecedented events that cause a large abnormal change in the data. In August of 2019 there was a fire that shut down a major processing plant. This caused cattle prices to decrease a significant amount because there was less overall per week capacity for cattle, creating an excess of fed cattle and lower demand and lower prices. Adding to this, packers raised prices of boxed beef meaning that fed cattle and boxed beef price series were moving opposite directions for several months. 2020 data was also excluded because a global pandemic began, which brought about inconsistent and varying prices and multiple shutdowns of plants throughout the year. If there was a significant time period after these events and the market was able to adjust to more of

an equilibrium this data could be used and this time period may be interesting to look at separately, but including it in this scenario creates a lot of outliers and results that likely do not represent the general relationship between the markets over time.

Methods

The following sections outline the methods and theory used to examine the relationship between the negotiated cash, CME fed cattle futures and boxed beef price series. The first step is to test for stationarity in each series individually. This test must be done first to ensure that the price series have the same unit root so that cointegration can be tested. If the series are cointegrated, then price discovery will be examined using a Vector Error Correction Model (VECM). An extra test that is being done in this study is one to test for the possibility of a break in the data or a regime shift where the relationships between the series change significantly. If a break is found, then the time periods before and after the break in data will be examined to determine whether there has been a significant change in the relationships between price series and their role in price discovery.

Stationarity Tests

Prior to doing a cointegration test, the futures, negotiated cash and boxed beef price series are individually tested for stationarity or identify the order of integration. If the series are stationary, that would indicate price variations are independent of the time or date. The stationarity test is done using the Augmented Dickey Fuller (ADF) test. Following Dickey & Fuller (1981) the ADF test uses the following regression model:

$$(1)\ \Delta x_t = \alpha_0 + \alpha_1 x_{t-1} + \sum_{i=1}^{n} \beta_i \Delta x_{t-i} v_t$$

where Δx_t is the change in price and x_t is the price level. The lag length *n* is determined using the Bayesian Information Criterion (BIC). This regression model is used to get the pseudo-*t* value for α_1 in the model. If the price series do fail the first ADF test with a t-value being

greater than the critical *t*-value, that means that they are non-stationary and there is a unit root to the price series.

To determine what the unit root is, an ADF test is performed on the differences of each price series. If the ADF test on the first differences indicate that the price series are stationary, that shows that the prices series have a unit root of one. If all of the price series have the same unit root, then they can be tested against each other for cointegration between the series.

Cointegration

If there is cointegration between the price series, that means that the non-stationary series have a long-run equilibrium relationship. To test whether there is cointegration between two variables, the Engel Granger (1987) method is most commonly used. This method uses an Ordinary Least Squares (OLS) model that looks like the following:

$$(2)\ \text{Standard Cointegration: } Y_t = \alpha_{0,Y} + \alpha_{1,Y} Z_t + e_{t,Y}$$

In this model, Y_t and Z_t represent two separate price series at time t, α_0 is the intercept, α_1 is the slope coefficient between the two series, and e_t is the error term that should be uncorrelated to time, or stationary. Using this model to determine whether the variables are cointegrated, the residual series of e_t is put into the ADF test. If the residuals are stationary, indicating that there is a unit root, then the variables Y_t and Z_t are cointegrated. This is a bivariate test, and the results of the test can depend on which price series is used on the left-hand and right-hand side of this. Due to this, it is important that 6 tests be run on the three-price series (negotiated cash, CME futures, and boxed beef series) so that all combinations can be tested for cointegration.

An alternative method to evaluate cointegration is Johansen's Cointegration Test (Johansen, 1988). The Johansen test adds to the Engel-Granger test in that it does not depend on

the order of the variables that are being tested and it can be used in both a bivariate and multivariate framework. The method used here follows that of González-Rivera and Helfand (2001) and Schroeder and Pendell (2006). The Johansen method tests for the number of cointegration vectors in the system by using the maximum eigenvalue and trace test statistics. The model for the Johansen test is as follows:

$$(3)\ \Delta y_t = \Pi y_{t-1} + \Phi_1^* \Delta y_{t-1} + \epsilon_t$$

To test for the number of cointegrating vectors, the Johansen test looks at the rank of Π. In this case there are n=3 price series, so there should be r=2 cointegrating vectors, or Π should have a rank of 2 if all of the price series are pairwise cointegrated. The null hypothesis for this test is that the number of cointegrating vectors is less than or equal to *r*, while the alternative hypothesis is that there exists more than *r* cointegration vectors. In this case, the test is run for *r* = 0, 1, and 2.

Regime Shift

With the thinning of the cash market that has been occurring over the years, there could be structural changes occurring in the relationships between the futures market, the fed cattle cash market, and even the boxed beef market. If there is a significant regime shift, then it is important to run the stationarity, cointegration, and VECM tests on the time periods before and after the shift to discover whether the time series have the same relationships in the different time periods, and if not, to see how the relationships have changed. To determine whether a structural break occurs a procedure developed by Gregory and Hansen (1996) and used by Pendell and Schroeder (2006) is used to test for the possibility of a regime shift. This method looks at the cointegrating relationship using OLS and residual based tests, similar to that of the Engle-Granger method in

equation (2). The Gregory Hansen based model that allows for structural change can be shown below:

$$(4)\ Regime\ Shift: Y_t = \alpha_0 + \alpha_1 D_t + \alpha_2 Z_t + \alpha_3 Z_t D_t + e_t$$

where Y_t, Z_t and e_t are defined the same way as in equation (1). D_t represents a dummy variable that is equal to 0 before the structural change and 1 after the change. The intercept before the structural change is α_0 and after is $\alpha_0 + \alpha_1$. The cointegrating slope coefficient is α_2 before the shift, and α_3 represents the change in the slope after the shift. The timing of the shift is unknown but can be found under the Gregory Hansen model endogenously. This is done by using statistical modeling to estimate the cointegration equations for all possible break points in the data and performing ADF tests on these equations. The break point, *k*, is the point where the ADF test statistic is maximized, meaning maximum cointegration. Once this break point is determined, the dummy variable, D_t is set to 0 when $t \leq k$ and 1 if $t > k$. For testing cointegration in this model that includes the shift, the ADF unit root test is applied to the regression errors in equation (4). The critical values for this ADF test are different than those of equation (1) and can be found in Gregory Hansen (1996).

The Gregory Hansen test is being applied to the relationship between the negotiated cash price series and both the futures and boxed beef price series. If a break is found in the data, the data will be split using a dummy variable and the relationships between the price series will be compared between the time periods before and after the break.

Vector Error Correction Model

To determine price discovery between two price series, the bivariate Vector Error Correction Model (VECM) developed by Gonzalo and Granger (1995) can be used. The

bivariate VECM uses the long-run equilibrium that is shown in equation (4) and can be written as follows:

$$(5)\ \Delta Y_t = \beta_1\left(Y_{t-1} - \alpha_{1,Z}Z_{t-1} - c\right) + \sum_{k=1}^{K}\Gamma_{YY,k}\Delta Y_{t-k} + \sum_{k=1}^{K}\Gamma_{YZ,k}\Delta Z_{t-k} + \varepsilon_{t,Y}$$

$$(6)\ \Delta Z_t = \beta_2\left(Y_{t-1} - \alpha_{1,Z}Z_{t-1} - c\right) + \sum_{k=1}^{K}\Gamma_{ZY,k}\Delta Y_{t-k} + \sum_{k=1}^{K}\Gamma_{ZZ,k}\Delta Z_{t-k} + \varepsilon_{t,Z}$$

where K is the lag length, the β_1 and β_2 coefficients represent the adjustment rate parameters which represents the speed of which the prices Y and Z return to the long run equilibrium, and ε_Y and ε_Z are the error terms. For example, if comparing negotiated cash prices with futures prices, Y_t would represent negotiated cash prices and Z_t would represent futures prices at time *t*. When considering equations (5) and (6) it is important to pay attention to the signs of the long run component. The portion in parenthesis should be positive in both equations. If the markets are converging and returning to their equilibrium relationship, then the signs of β_1 and β_2 should be opposite, with β_1 being negative and β_2 being positive. If there is convergence, you can then use these β_i coefficients to examine price discovery between the markets.

To get an idea of each market's role in price discovery, a procedure created by or expanded by Schwartz and Szakmary (1994), Gonzalo and Granger (1995) and Theissan (2002) is applied. This method calculates values for price discovery information using the relative ratio. This ratio uses adjustment coefficients, β_1 and β_2 and is shown as follows in equation (7).

$$(7)\ \theta_1 = \frac{|\beta_2|}{|\beta_1| + |\beta_2|}\ \ and\ \ \theta_2 = \frac{|\beta_1|}{|\beta_1| + |\beta_2|}\ and\ \theta_1 + \theta_2 = 1$$

A large θ_1 would mean a small β_1, which means that market *i* is slowly responding to the shocks that occur in the market. This would imply market *i* is the price discovery leader that is being used as a reference market (Wright 2017). This testing method of using the VECM to calculate the relative ratio will be performed on the whole data set, and then again if a regime shift is present, before and after the break to see if the relative ratio of adjustment is different before and after the break. This will indicate whether there have been shifts in price discovery between the futures and cash market, the futures and boxed beef market, and the cash and boxed beef market.

Results

The results follow the order used in the research methods with the exception of the regime shift being introduced in early tests results. This is because a structural break in the data occurred in June of 2016, so the full data set is being tested as well as the subsets of data before and after the break. The results of the stationarity test and the bivariate and multivariate cointegration tests will be laid out.

Stationarity

In order to compare and analyze the price series data, each series had to be tested for stationarity to determine whether there was a unit root. The ADF test was used to test this, with the null hypothesis being that the series are nonstationary and the alternative hypothesis being that the prices are stationary. The results of the ADF tests can be seen in **Table 4**, which shows

Table 4: Augmented Dickey Fuller (ADF) Stationarity Test on Weekly Individual Price Series, 2002-07/2019

Time Period	Variable	Test Statistic	P value	1st Diff Test Statistic	P value
2002-2019	**Negotiated Cash**	-2.10	0.5445	-20.30	0.0000
	Futures	-1.97	0.6152	-18.96*	0.0000
	Boxed Beef	-3.06	0.1163	-18.06	0.0000
2002-04/10/2016	**Negotiated Cash**	-2.48	0.3374	-18.35*	0.0000
	Futures	-2.56	0.2991	-17.15*	0.0000
	Boxed Beef	-2.93	0.1551	-16.91*	0.0000
04/17/2016-07/2019	**Negotiated Cash**	-2.34	0.4099	-8.76*	0.0000
	Futures	-2.71	0.2340	-8.47*	0.0000
	Boxed Beef	-2.52	0.3163	-6.37*	0.0000

Source: Calculated using LMIC AMS data

Note: The critical value for the one-sided ADF t-test at 99% significance level is -3.96.

* indicates significane at a 99% level

that all of the price series are nonstationary, meaning that the prices are not independent of time and are changing. The table also shows that the ADF tests performed on the first difference of the price series indicated a unit root of 1 for all three of the price series. The results of the ADF tests on the first difference show that the first difference is stationary over time, which indicates that there is a unit root of one, or I(1), for all price series.

The tests were also run for the subsets of data in the time before and after the break in data (June 2016). The results of these tests can be seen on the bottom part of Table 4 and they are consistent with the results of the entire time period meaning that none of the price series are stationary and all have a unit root of 1. Since all of the price series have the same unit root, they can be tested for cointegration amongst each other to determine whether the prices are moving together over time.

Cointegration Tests

After using the ADF test to ensure that all of the price series have the same unit root, the Engle-Granger bivariate and the Johansen multivariate tests were able to be used to analyze the relationship between the markets and test for cointegration. Before testing for cointegration, it can be valuable to examine the basic correlation between the time series. The results of this can

Table 5: Cross Correlation Coefficients Between Price Pairs for Full Time Period and Two Subsets

Price Pairs	Full Time P0000eriod (2002-07/2019)	Time Period 1 (2001-04/17//2016)	Time Period 2 (06/2016-2019)
Cash/Futures	0.991*	0.994*	0.884*
Cash/Boxed Beef	0.957*	0.984*	0.679*
Futures/Boxed Beef	0.942*	0.977*	0.558*

Source: Calculated using LMIC AMS data

* Indicates significance at a 99% level

be shown in **Table 5,** which shows significant correlation for the entire time period and each of the two sub periods at a 99% level. Looking at these results it can be seen that the time series are always positively correlated, but it is also clear that the time series are relatively less correlated in the second time period., particularly with the boxed beef price series This would suggest that there is more variation between the prices in recent years.

Next, the Engel Granger bivariate cointegration test was performed. Under this test, the hypothesis being tested is that there is a cointegrating vector between the two-price series. If this is true, then the residual of the cointegrating regression should be stationary, which can again be tested using the ADF test. The results of this test can be shown in **Table 6** in the Model 1 test statistic. In this case, Model 1 is referring to the test on the entire time period without allowing for the possibility for a break in the data. There are a total of six tests run in this model because

Table 6: Augmented Dickey-Fuller Cointegration Test Results of Weekly Negotiated Cash, Futures, and Boxed Beef Prices, 2002-07/2019

Dependent Market/Independent Market	Model 1 (No Regime Shift)	Model 2 (With Regime Shift)
Negotiated Cash/Futures	-7.23*	-7.47*
Negotiated Cash/Boxed Beef	-3.67*	-6.49*
Futures/Negotiated Cash	-7.21*	-7.54*
Futures/Boxed Beef	-4.07*	-6.73*
Boxed Beef/Negotiated Cash	-3.74*	-6.61 *
Boxed Beef/Futures	-4.16*	-6.83 *

Source: Calculated using LMIC AMS data and equations 1 and 4

* All models were significantly cointegrated at a 99% confidence level

Note: Model 1 is the ADF test for the entire time period (2001-2019) without allowing for a regime shift, while Model 2 is the same time period but does allow for the regime shift that occurs in June of 2016

the order that the series are regressed can have an impact on the results. The results of the test ADF test for all of the bivariate models reject the null hypothesis of no cointegration.

To confirm these results and to also look at the price series under a multivariate test, the Johansen test was performed. This test indicated that there were two cointegrating vectors between the three-price series that were being tested. The results of cointegration hold for the entire time period without allowing for the possible regime shift, so it is not mandatory that the shift be tested to determine cointegration. That being said, considering a regime shift can shed light on a possible change in the cointegrating relationship and can provide additional information for price discovery.

Bivariate cointegration tests that allow for the regime shift were performed and are represented by the Model 2 results in **Table 6**. Under these tests the null hypothesis of no cointegration was rejected at a 99% confidence level, meaning that the cash, futures, and boxed beef markets are cointegrated when allowing for the structural break. The Johansen tests was also applied to the time period before and after the regime shift, and the results here also reject the null hypothesis of no cointegration at a 1% level. Therefore, the negotiated cash, futures, and boxed beef markets are all cointegrated throughout the entire time period as well as before and after the regime shift.

Regime Shift

The Gregory Hansen test was performed on the data to determine whether there was a regime shift throughout the time period. This test was run using a model where the negotiated cash market was the dependent market and the independent markets were the futures and the boxed beef markets. The results of this test indicated that there was a significant break in the

Table 7: Parameter Estimates from the Regime Shift Model (Model 2 from Table 5) for Each Weekly Price Series Relationship for 2002-07/2019

Dependent/Independent market	α_0 **Intercept**	α_1 **Post shift dummy**	α_2 **State**	α_3 **Post-shift coefficient**
Futures/Neg Cash	- 2.566 **	18.688**	0.964 **	-0.171**
	(0.000)	(0.000)	(0.000)	(0.000)
Futures/Boxed Beef	-5.762**	55.064**	0.665**	-0.342**
	(0.000)	(0.000)	(0.000)	(0.016)
Neg Cash/Boxed Beef	-8.774**	37.780**	0.691**	-0.252 **
	(0.000)	(0.000)	(0.000)	(0.000)

Source: Calculated using LMIC AMS data and equation 4

data in April of 2016 meaning that the model structure changed. This result means that the time period before the break could have a different intercept and regression coefficient than the time period after the break, so both time periods should be examined to compare the way that the subsets of data interact compared to the entire data set.

This test is being run as a bivariate test and looks at the relationship between the negotiated cash and futures markets, the futures and boxed beef markets, and the negotiated cash and boxed beef markets. The results of this OLS test that allows for the regime shift can be seen in **Table 7.** The key values of interest in these results are α_2 and α_3 as they are the regression coefficients for the relationship between the two models. The results show that the coefficients are significant for all 3 models at least to the 5% level. Combining the results from the cointegration test and the OLS test, they show that the series are all cointegrated with the shift, and that there is a significant change in the cointegration relationship after the regime shift. These results hold for all of the models which would indicate that the price discovery relationship may have also been impacted by the regime shift.

Vector Error Correction Model and Price Discovery

With the findings of the regime shift and the cointegration in all time periods, the Vector Error Correction Model can be implemented to help quantify how the relationships of the price series differ before and after the structural change occurs. The price discovery relationship is being looked at using the results from **Table 8** which is calculated using equation (7); the Gonzolo Granger method. This method calculates the relative ratio of each price series, such that $\theta_1 + \theta_2 = 1$. A higher relative ratio number (θ_i) for a price series indicates the dominant market when it comes to price discovery.

Looking first at the results of the test on the entire time period, 2001-2019, it can be seen that the futures market is the clear leader in price discovery over the cash market. The other two relationships, between boxed beef and the futures and negotiated cash markets, show no

Table 8: Relative Ratio for Price Discovery Between Each Weekly Price Series Relationship in Each Time Period, 2002-07/2019

Time period	Price Pairs	Adjustment Coefficients		Relative Adj. Coefficients	
		β_1	β_2	θ_1	θ_2
Full Time Period (2002-08/2019)	**Cash/Futures**	-0.190	0.010	0.05	0.95
	Futures/Boxed Beef	0.003	0.077	NC	NC
	Cash/Boxed Beef	0.010	0.0844	NC	NC
Period 1 (2002-04/2016)	**Cash/Futures**	-0.180	0.022	0.112	0.888
	Futures/Boxed Beef	-0.007	0.185	0.964	0.036
	Cash/Boxed Beef	0.011	0.244	NC	NC
Period 2 (04/2016-08/2019)	**Cash/Futures**	-0.207	0.036	0.148	0.852
	Futures/Boxed Beef	0.020	0.107	NC	NC
	Cash/Boxed Beef	0.043	0.072	NC	NC

NC represents non convergence meaning that if the leading market moves from equilibrium, the other market does all of the adjusting. This means price discovery only takes place in the leading market.

Source: Calculated using LMIC AMS data and equations 5, 6, and 7

convergence. This is seen because their adjustment coefficients, β_1 and β_2 do not have opposite signs (positive and negative). This means that when there is a change in the markets, boxed beef is doing all the adjustment and not providing feedback for price discovery.

Splitting the data at the point of the structural shift and running the same tests over each time period shows similar results. The futures market continues to dominate price discovery, but in both subsets the cash market does have a larger role. In the early time period, the cash market has 11.2% of the weight of price discovery and in the second time period it has increased to be 14.8% of the weight. That said, the futures market is still largely dominant at over 85% of the weight. The significant difference between the weights of the adjustment coefficients and the full time period and each subset both further supports the finding of the break in data and also sheds light on how sensitive the relative adjustment coefficients are.

The boxed beef price series continues to show no convergence with either market, with the exception of the futures market in the earlier time period. While there is convergence between the markets in this time period, boxed beef is still providing very little feedback with only 3.6% of the weight of price discovery.

Conclusions

Negotiated cash markets for cattle have always had an important role in price discovery, but as the market continues to thin, that role may be changing. Examining price discovery relative to the futures market for fed cattle is a large topic of interest and has been a focus of previous studies, but as the market has changed over the last few decades, it is important to look at the impact that these changes may have had. This research addresses the cash and futures relationship while also looking to see whether the role of more downstream products such as boxed beef has been impacted.

In approaching this research, it is vital to have a good understanding of the U.S. cattle market and the changes that have occurred over the past few decades in the ways that cattle are being sold. With about a 40% decrease in volume of cattle sold on the cash market over the past 15 years, the decreasing information and representativeness amplifies the significance of understanding the cash market's role in price discovery.

To examine these changes, bivariate cointegration tests are used to look at the price relationships between weekly futures prices and the weekly negotiated cash markets for the 5 regions. Before testing for cointegration, stationarity had to be looked at. Using the Augmented Dickey Fuller test, all of the price series were nonstationary, meaning that they change over time, and all had a unit root of one. From here the Engle-Granger bivariate and Johansen multivariate tests showed a long-run cointegration relationship did exist both between the futures and cash market and the futures and boxed beef market. The Gregory-Hansen bivariate test indicated that there was a structural break in the model that caused significant differences in the relationship between the futures and cash markets. This break was indicated to occur in April of 2016. With

and without the break in data being included, the markets were highly cointegrated. This indicates that even though the cash market is thin, it is still very cointegrated and closely related to the live cattle futures market. The boxed beef market was integrated with the negotiated cash and futures market both before and after the break in data was included, indicating that these markets are also closely related.

There is no obvious reason for the timing of this break in the data and change of relationship, but there are a few things that could be factors. Towards the end of 2015 and through 2016 the cattle market experienced a large decrease in prices. This significant shift could have altered relationships and further encouraged hedging cattle in the futures market. Another thing to notice is that the break occurs after the market structure went through the large decrease in cattle marketed using the negotiated cash market. At the time of the break in April 2016, the weight of cattle marketed by the various methods had become more steady, so that could also be a reason for the timing of the break.

Results of the study show that the futures price is the relevant and leading market in price discovery over the entire time period compared to the negotiated cash market. When looking at the two subsets of data before and after the break in data occurred, it shows that the cash market is having an increasing role in price discovery. This result comes unexpectedly because the theory would be that as the cash market thins, it would be used less to inform the futures market. Despite this surprising increase, the result should not raise too much concern as the big picture still shows that the futures market has over 85% dominance in price discovery. The subset, particularly the later time period, are also smaller in size making it more difficult to get more accurate results, so this could be another thing to consider when looking at these results.

Boxed beef is shown to have little or no role in price discovery. The adjustment coefficients between this series and both the negotiated cash and futures markets shows no convergence, meaning that the other markets do not adjust to changes in the boxed beef market, the boxed beef adjusts to them. In all other tests, the boxed beef market was found to be cointegrated and strongly related to other markets. That said, **Table 5** does indicate a decreasing correlation between the boxed beef market and both other price series. Between that result, and **Figure 4** and **Table 1** showing large variations in the spread between beef sold at different levels (farm, wholesale, and retail), there is clearly more to the relationship between boxed beef and the other markets. Something that may be interesting to look into for future studies would be that margin of difference between boxed beef and cattle prices to better understand where the difference comes from and what may be driving the variations or changes in trend over time. Another takeaway from this unsteady relationship between markets is that while the other markets may lead in price discovery, they should not be solely used for price discovery of boxed beef. This means that formula pricing with boxed beef would not be very efficient using the other markets to determine the price unless the margins of difference between boxed beef and those markets is better understood and accounted for.

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