# Price discovery in cattle and measuring market thinness

by

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# Abstract

Economists and market participants have long been concerned that declining participation in negotiated cash sales of live cattle could have adverse impacts on the cash market and beyond. Economic incentives have led to a shift toward formula trading and this shift has left a relatively small group to carry the load of total cash negotiations. It is presumed that negotiated cash prices are used as base prices in formula sales meaning that the 65% of cattle sold via formula are priced based on 21% of live cattle sold as negotiated transactions (USDA Livestock, Poultry, & Grain Market News, 2019). The goal of this paper is to determine how thin the negotiated cash market for live and dressed cattle, as well as the beef cutout, can become and still represent an accurate market price. Following previous work in market hogs and live cattle markets, I applied Chebyshev's inequality to weekly negotiated live and dressed cattle sales in the five major price-reporting regions and the beef cutout to determine the number of transactions needed to arrive at a price that meets an acceptable accuracy criterion. I extended the method to consider average annual transaction levels, as others have done, but also weekly levels. In both cases, I show at what points in time regions have or have not had sufficient negotiated trade to maintain pricing accuracy. Results show that outside of certain market shocks in 2003 and between 2014 and 2017 there continues to be sufficient trade in the negotiated cash market.

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# Acknowledgements

Thank you to Dr. Brain Coffey, my major professor, for helping me find a topic that was interesting and pushed me to grow. Thank you also to my other committee members Dr. Ted Schroeder and Dr. Glynn Tonsor, who have both provided insight and support on this project. Lastly, thank you to all my family and friends who have supported me in my throughout my academic endeavors, especially my parents.

# Chapter 1 - Introduction

## 1.1 Background

As the cattle industry has evolved and grown so have the methods by which cattle are traded. Over the past 30 years, there has been a significant shift in how the industry buys and sells cattle. At the most basic level, price discovery occurs when a potential seller and a potential buyer negotiate to determine a price. This type of transaction requires some search cost, transportation cost, and creates an opportunity for one party to have more bargaining power depending on their size. Formula trades on the other hand do not require as much work. Formula trades require some kind of base price that has already been discovered, and different premiums or discounts can be built in, to account for volume and quality grades. This form of trading is much more efficient for both the packers and feeders because it eliminates the need for weekly price discovery or showlists. What is causing a sense of unease in the industry is the extreme transition from cash negotiations to formula trading. If the cash market is being used as the base price for formula trading and fewer and fewer cattle are being trading in the cash market, the validity of the base price comes into question. The other types of marketing strategies are forward contracts and grid negotiations.

Several researchers have attempted to determine the implications of a thinning market and this paper hopes to build on the research that has already been done in hogs (Franken & Parcell, 2012) and cattle (Tomek, 1980, Ward & Choi, 1998, and Koontz, 2015) . In 2001, the Livestock Mandatory Price Reporting Act (LMR) was passed and created more market information for both feeders and packers. However, since the LMR was put in effect, cash negotiations have continued to decline and nothing else has seemed to change. In 1980, William Tomek explored the use of Chebyshev's Inequality to measure market thinness. Following the

previous use of this inequality, this study will attempt to measure market thinness and determine how thin markets can become while still representing market conditions. This study will evaluate the live and dressed 5-Area market and regional markets as well as the beef cutout to show along the value chain how many transactions are required for a representative market.

**Figure 1**[1]

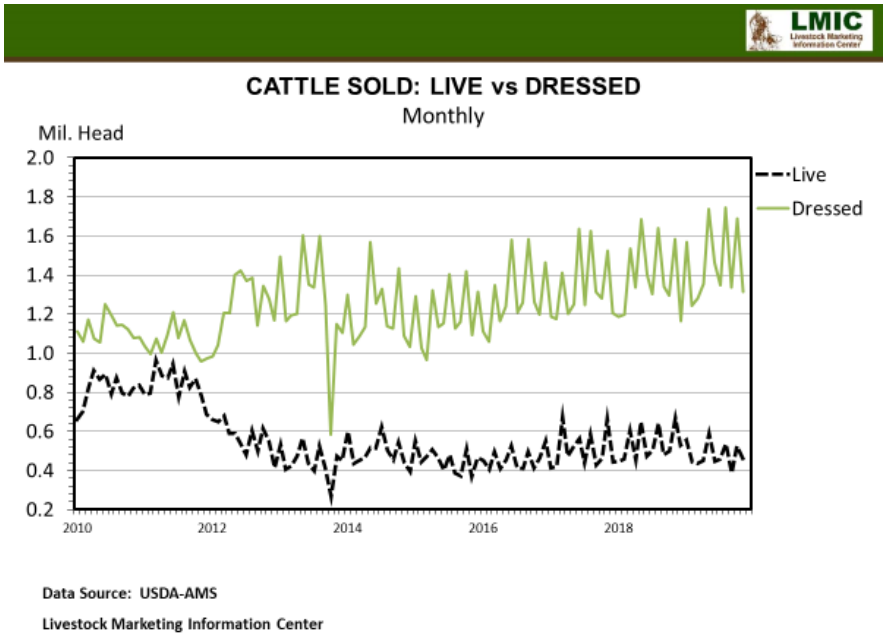



**Figure 1** shows the increase of dressed cattle sold in comparison to live cattle; this is important when measuring market thinness in each market. The live and dressed markets are evaluated separately and then combined to show total negotiated cash transactions. Each regional market is also examined at on an individual basis and on a paired basis in order to compare the accuracy of regional markets' prices. **Figure 2** shows head of cattle on a yearly basis that are traded in each region between 2002 and 2019. As the graph shows, the Texas-Oklahoma-New Mexico market has decreased substantially over the past 18 years. This is concerning in that Texas has the most cattle in the market, but they are not contributing to price discovery. The Nebraska market has been used in several studies as the base market for price discovery and this study will continue

[1] This figure shows total trade not just cash negotiated trade.

that due to the consistency of price discovery occurring in that market as compared to the other regions.

**Figure 2**

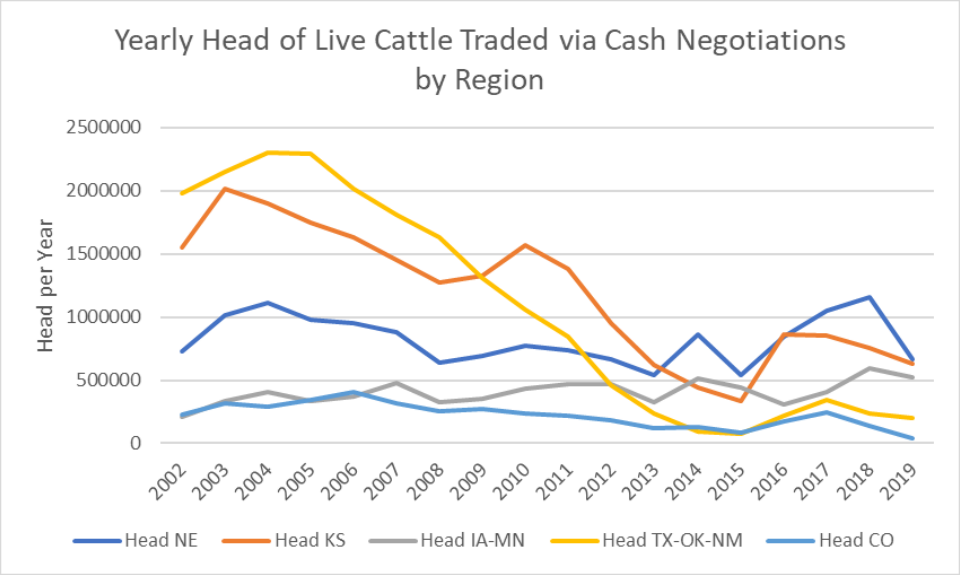
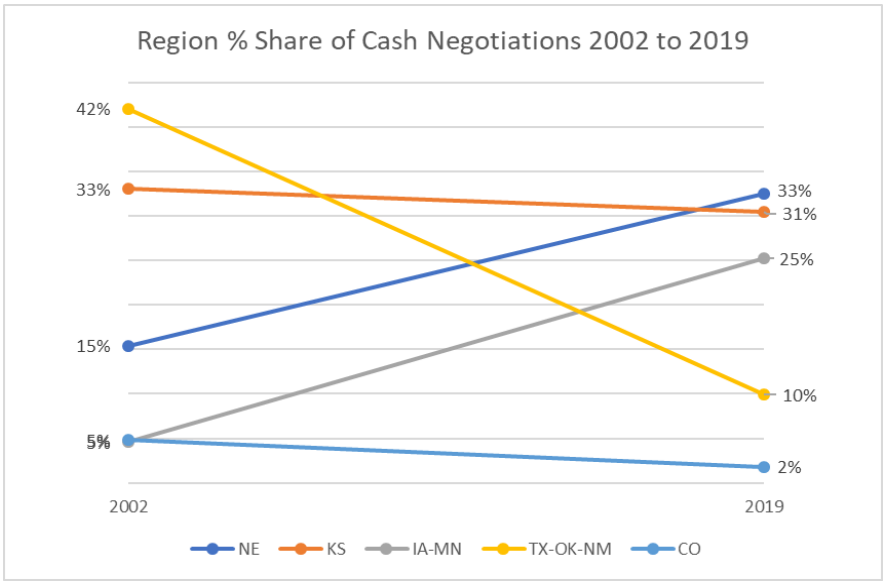



**Figure 3** shows how each region has changed in terms of % share of total cash negotiations from 2002 to 2019. Looking at these two points in time, since 2002, Nebraska and Iowa-Minnesota have increased, Texas etc. and Colorado have decreased, and Kansas has stayed about the same.

**Figure 3**



## 1.2 Problem Statement

For years the question that has been surrounding this topic is how thin is too thin? There have been many discussions on how thin a market can become before it no longer is representative of the true market conditions. Though other studies have used more sophisticated models to consider specific aspects of this question, Chebyshev's inequality offers a specific definition of a thin market and allows for different levels of probability and accuracy that the price will be close to the unknown equilibrium price. The goal of this study is to evaluate each of the regional cattle markets as well as the overall market to determine, using Chebyshev's inequality, how thin each market can become before prices are no longer representative of market conditions.

## 1.3 Justification of the Study

This study adds to the previous work on this topic by offering and alternative way that the variance in Chebyshev's inequality can be defined while comparing it to the definitions already explored in past studies. Additionally, the second manipulation of the inequality allows for more discussion on the pricing accuracy within this thinning cattle market. All live and dressed cattle markets with the beef cutout are used to show how each market, that can be used as a base price for formula trading, reacts to the declining cash transactions. The thesis will be split up into 5 chapters. The first chapter has defined the basic background and motivation for this study. The second chapter will cover literature on alternative marketing arrangements, the mandatory price reporting act, price discovery, market shocks, and Chebyshev's inequality. The third chapter will cover the methods and data used and the fourth chapter will cover the results and analysis. Finally, the fifth chapter will be conclusions and discussion of limitations and suggestions for continued work on this topic.

# Chapter 2 - Literature Review

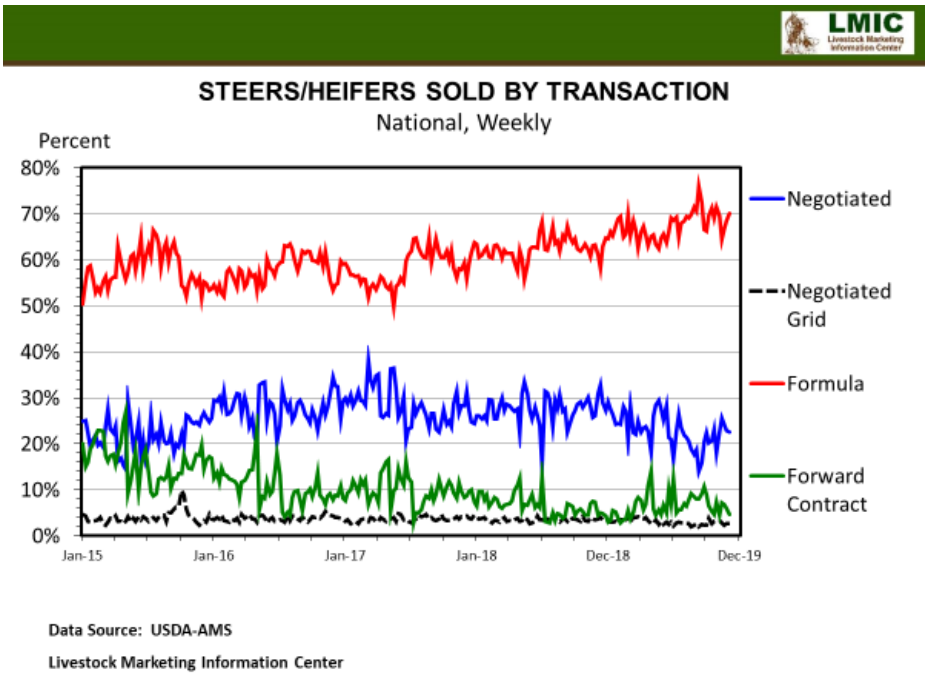
## 2.1 Alternative Marketing Arrangements

According to Ward et al., 1999, formula and grid trading gained interest from large feeders and packers in the late 1980's. Formula in simplest terms means that the final price is established using a formula that add premiums and subtracts discounts from a base price . What is most important when understanding formula trading for this discussion, is that formula pricing is based on existing market information and does not contribute to new price discovery. Grid pricing can use a formula price as its base price and then have premiums and discounts for cattle who are above or below the standard. Though grid and formula prices often go together, grid prices are not always based off a formula price and formula prices do not always use a grid. Ward et al., 1999, lists several sources that the base price can be found; average price for the cattle scheduled to be slaughtered that week or week prior, market reports from the week prior, boxed beef cutout, nearby futures price, and negotiated cash price. The negotiated cash price however, is related to all of these other methods so in reality the negotiated is relevant for the base price in any formula trade. This is why having accurate price discovery is so important.

The base price issue also reflects the quality of cattle from which it was derived. Since grid pricing can offer certain premiums for higher quality cattle, many of the higher quality cattle have been marketed this way and have been diverted from the negotiated market. The issue comes in when the base price being used includes lower quality cattle to market higher quality cattle. This is not the case for all cattle, but it occurs often enough that it has become a topic of research and discussion. Not all grid prices rely on a private formula price and can be discovered. However, like cash negotiations, negotiated grid is more expensive to discover and as seen in

**Figure 4,** there are very few negotiated grid transactions as compared to the other forms of marketing arrangements.

**Figure 4**




## 2.2 Mandatory Price Reporting Act

LMR went into effect in April 2001 and required plants that slaughter 125,000 head of cattle or more to report information concerning pricing, contracting for purchase, formula sales, and supply and demand conditions twice a day to the Agricultural Marketing Service (AMS) (Pendell & Schroeder, 2006). This report has helped provide more market information for all market participants. Pendell and Schroeder used Engle-Granger bivariate and Johansen's multivariate cointegration[2] tests to determine if the prices in the five major reporting regions

[2] Cointegration is a statistical property that analyzes whether a collection of non-stationary series, in this case price series, are related in the long run. This is important when preforming price analysis so that we can understand how prices in different regions are different from each other over time.

were cointegrated in the long run. The study determined that these markets are highly cointegrated in the long run both before and after the implementation of LMR.

Bashir et al. evaluated the relationship between the implementation of LMR and price dispersion which they define “as the intra-week price spread for a specific grid premium or discount between packing firms that are reporting their grid price schedules to the AMS”. Fausti et al., 2010 comes to the conclusion that LMR, though it did cause some volatility in the premiums and discounts in grid pricing after implementation, was overall important for transparency within the market. Chung et al., 2018 show the farm, wholesale, and retail beef prices before and after the implementation of LMR and there is clearly more variability in prices post-LMR. However, this may not be a direct result of the report, rather repercussions of the global food crises in 2007 and 2008 as well as other market shocks that occurred between the report’s implementation and 2015. Chung et al. through several bivariate and multivariate tests, demonstrate how the beef supply chain has experienced faster speed of price transmission post-LMR. Higher speeds of price transmission are important for market participants and policy makers to help improve market competition and price discovery.

## 2.3 Price Discovery

Over the years there have been studies on the importance of price discovery and how changes in one market can affect another related market. Coffey et al., 2018, evaluated the relationship between the live cattle cash prices and the related futures market by measuring changes in basis prediction error (BPE). BPE is “the difference between actual and expected basis”. In their results it was reported that the change in negotiated shares is positively related to BPE and they move together. The thinning cash market can create discrepancies between the

expected price that producers receive and the actual price making hedging a less effective risk management tool however, they found that it was not the most significant factor and that there are regional factors such as average weight or delivery cost that can have a larger impact on BPE. These regional differences make it paramount for producers to be aware of their specific market when using risk management tools like a futures contract. By evaluating each regional market's level of thinness this study will continue the emphasis on regional information as well as the market as a whole. Schroeder et al., 2019, continues the conversation on basis risk. They define basis risk generally as " the amount of unexpected variability in local market basis realized at the time a hedge is liquidated." The absolute basis errors are reported that compare the negotiated cash sales to grid sales that included higher Choice cattle. Overall, they see a higher basis risk in cattle sold on the grid over the 10-year period between 2008 and 2017. As the quality diverges between the cash market and the grid, basis risk can increase, and hedging becomes a less effective risk management tool. A solution proposed in the study is "a composite fed cattle value index," which includes negotiated cash, formula, and negotiated grid. The other option mentioned that may hold value in the future is Blockchain technology, especially when considering the desire for privacy.

In the USDA Daily Boxed Beef Report, authors of this report aim to help market participants better understand what the cutout is and how the cutout is calculated. In the boxed beef report, it is claimed that the beef cutout may be a source of future basis for price discovery. It is important to note, that this report like the live and dressed cattle do not report which loads were sold at which price. Joseph et al., 2013, look at price discovery and how the futures, fed cash, and the boxed beef prices interact with each other within the overall U.S. cattle market. According to the directed acyclic graphs contemporaneous causality, there is an order for which

market is most influential futures then fed cattle then boxed beef. They find that although the boxed beef price has influence in the long-run it is not important in the short-run for price discovery and may not be a good alternative for price discovery as originally thought. A work that goes farther into the use of the boxed beef report, and its relationship to the futures market, was done by Joseph et al., 2016. For this study they combine the Choice and Select values and weight them based on quality, 55% for Choice and 45% for Select. They also put the cutout value in terms of live animals due to the futures contract is for live cattle. The results of their study show that the futures market responds faster to new information than the cutout. One of the issues with the boxed beef report is how few transactions are included. As Joseph et al., 2016 point out exported beef and branded products such as Certified Angus Beef are not included in the cutout value or load volume which means a large portion of transactions are not accounted for within the report. This may lead to an inaccurate value of the wholesale meat market regardless of how thinly traded it has become.

### 2.4 Market Shocks

Over time the beef industry has experienced different market shocks, these shocks can influence price behavior. This section provides contexts for the extreme changes in the market. The BSE outbreaks in the U.S., especially in 2003, was one of the most notable market shocks in the beef industry. In Tejeda et al., 2018, short run shock effects are evaluated using a rolling Error Correction Model (ECM) focusing specifically on the BSE outbreaks. They discuss how the first BSE outbreak caused a change in the reference price in the market from futures to cash however, the reference price reverted back to the futures price about a month before bans on trade were partially lifted. The trade bans by Japan and South Korea were an unexpected shock that occurred after the first outbreak. The second and third outbreak did not experience a change

in the reference price nor were there any trade bans inflicted after the outbreaks. Results show that the 2003 outbreak was by far the largest shock to the market of all the outbreaks. One of the largest concerns of the BSE outbreak were safety shocks and Sayed Saghaian discusses the dynamics of vertical price adjustment within the beef sector (Saghaian, 2007). He determines that the wholesale market was faster to adjust than the retail market after the beef safety shock. The feedlot and wholesale levels took the brunt of the shock compared to the retail level and this may be due in part to an imbalance of power between retailers and wholesalers.

## 2.5 Chebyshev's Inequality

Chebyshev's Inequality has been used several times to determine market thinness. The inequality consists of the probability that the deviation of the mean prices (intraday, daily, or weekly) from the true or equilibrium price falls within a particular pricing accuracy. The number of transactions, *n*, is what is of interest to insure that at a high probability, prices do not fall outside of the accuracy range. By comparing the number of actual transactions occurring in the market and the number of transactions needed, we can determine if there are sufficient transactions to represent the market. It was first used my Tomek in 1980 to compare the terminal Denver market to the market in Omaha for live cattle. Tomek goes in depth into the use of the $1^{st}$ differences estimation of the variance which helps to show the deterioration of the Denver market as opposed to the Omaha market which serves as the proxy for the national market. Tomek concludes that thirty to thirty-five transactions were required per week were sufficient under the 1960's market conditions for accurate price discovery in Denver. However, he cautions the reader to take this number with a grain of salt for a couple reasons. First this number depends on the 1960's market conditions and does not serve as a standard across time. Secondly, this

estimate is based on the standard of precision staying within $0.10 per hundredweight which can easily change if there are any shocks or changes in market structure.

In 1998, Ward and Choi used Chebyshev's inequality with data from the *Fed Cattle Market Simulator* to explore relationships in price reporting accuracy. This study is very different than the others using the same equation in that the transactions are not actual transactions from the market but simply a representation of how the market could react to certain conditions at the time. They follow what Tomek did and took it further by solving not only for number of transactions needed at a given probability and pricing error but solved for the probability and pricing error themselves. The probability gives the likelihood that the price will fall within the pricing error range at the to show how market deterioration could occur, three different scenarios where tested which reduced the number of transactions in the market.

In 2012, Franken and Parcell revisited Chebyshev's inequality to evaluate market thinness in hogs and pork. They followed Tomek's work fairly closely however, they compare negotiated hogs to the national carcass cutout. One of the key points that Franken and Parcell address is the quality concerns of hogs traded in the cash market as opposed to other marketing arrangements. Franken and Parcell suggests that the St. Joseph market need not rely solely on their own volume for price discovery since the Iowa-Minnesota market has sufficient price discovery. However, this principle may not apply to the cattle market as easily since the market conditions are not as similar between the five regional beef markets as these two hog markets. Franken and Parcell take it one step further than Tomek in that they also evaluate the quality concerns of the hogs traded through cash negotiations. They determine that the declining number of hogs sold in the cash market maybe the reason for a decrease in quality of these hogs. Overall

improvements in genetics in the industry may also contribute to the decrease in lower quality hogs being sold in the market regardless of marketing arrangement.

While defining thinning markets and policy implications, Koontz, 2015 uses Chebyshev's inequality as an empirical way to measure market thinness in the five regional fed cattle markets, boxed beef, and futures market. Unlike, Tomek and those before him Koontz uses a vector error correction model (VECM) to show the multilateral relationship between these seven markets rather than the typical bilateral relationships that others have used. Using a unit root test, he confirms that the seven price series are nonstationary and using the Johansen test he proves that the prices are cointegrated. With the predictions and residuals from the VECM, Koontz estimates, on a monthly basis, the transactions needed for accurate price discovery. He uses the VECM to measure the variance instead of the 1$^{st}$ difference method which differs from the previous work with this inequality. Koontz also explores the influence that the probability has on transactions needed at 80% and 95%. As can be expected, with a higher probability the transactions needed go up and the opposite occurs when the probability is lower. This creates a need for market participants to decide how accurate they want the market to be. He comes to the conclusion that for individual, alternative methods of marketing cattle outweigh the benefits of having a thicker cash market. This is not necessarily the case for the market as a whole and the issue of market thinness continues to be an important topic of conversation for market participants and policy makers alike.

# Chapter 3 - Data and Methodology

## 3.1 Methods

As a market participant there is the hope that the market is efficient and responds accurately to change. When markets become thinner, confidence in reported prices and market activity can become low. Tomek in attempting to understand price behavior used Chebyshev's inequality as a way to empirically measure market thinness. This inequality does not give a definitive answer to "how thin can the market get" but it does help to show the gravity of the market thinness issue.

Using Chebyshev's inequality, *n* is the number of transactions need at some high probability level P in order to assure that the daily, or in this case weekly, price $X_n$ does not deviate from the equilibrium price μ within a certain level of accuracy ± *c*. Therefore,

$$(1) \quad P(-c \leq X_n - \mu \leq c) \geq 1 - \frac{\sigma^2}{nc^2}$$

The variance is $\sigma^2$ which is the distribution of prices over time. By rearranging the equation, we can find *n* which is the number of transactions.

$$(2) \quad n = \frac{\sigma^2}{(1-P)c^2}$$

The higher the *n*, the more transactions needed to have a representative market. Additionally, the higher the desired level of accuracy, the number of transactions goes up. For the purpose of this paper $X_n$ is assumed to be equal to μ since the true mean is unknown. One of the points of contingency in Chebyshev's inequality is how to define $\sigma^2$. In this paper there are three methods used to calculate the variance. First, the sample variance of the price is taken for each year. Secondly, following the work of both Tomek and Franken and Parcell, a first differenced equation is used as a pairwise measure of the variance:

(3) $y_t - y_{t-1} = \mu + \beta(x_t - x_{t-1}) + \upsilon_t$

where $y_t$ and $x_t$ are the individual region prices and $\upsilon_t$ is the error term in time *t*. The Augmented Dicky-Fuller as a test for non-stationarity, the prices are non-stationary for the individual price series and stationary in 1st differences. The estimated variance of μ is the measure for $\sigma^2$. Lastly, taking one variance for a year causes prices from December of that year to affect the prices from January. This is a problem when there is one event during year that can cause the variance to be unrepresentative of what is happening week to week. To account for this, a quarterly rolling variance is used to reflect current forces in the market. With these 3 measures of $\sigma^2$, this study hopes to add to the previous work by comparing the different measures of the variance.

Another manipulation of Chebyshev's original equation allows us to calculate the level of accuracy *c* with the following equation:

(4) $c = \pm \frac{\sigma}{\sqrt{n * (1 - P)}}$

where *n* is the number of actual transactions and σ is tested with all three measures used to calculate the variance. The purpose of this additional manipulation is too better gauge the range of accuracy so that it is not arbitrary. When solving for *n* Chebyshev's inequality allows us to see what *should* be occurring in the market but for *c*, we use what has actually occurred and how that changes the range of accuracy.

## 3.2 Data

Data was collected from Livestock Marketing Information Center (LMIC), who archives the reports from the USDA AMS, for weekly cash negotiations from 2002 through 2019 for the 5-Area market and individual state markets. The beef cutout data was also collected from LMIC from 2004 through 2019. All the data used was collected after the implementation of LMR, so there were no adjustments made to include previous years. For each market, steers and heifers were combined to provide a better representation of the total transactions of live and dressed cattle. The data is reported on a per head basis, as transaction size is not public information; therefore, in order to create a standard transaction size an informed average transaction size of 40 head was used. The transaction size itself is an assumption and a transaction size of 120 was also used in order to compare a smaller lot of cattle with a larger one. Using one size over time is also an assumption that transaction size stays constant however, this is not the case. It is important to note that transactions should be measured and not head to best mimic actual market conditions. Adjustments were made to combine the dressed and live cattle prices and weights by putting the dressed data in live equivalent terms. These adjustments were only made when combining the two series otherwise, the dressed data was measured in its original form. For the beef cutout, prices and loads for choice and select were combined. The loads do not necessarily match up with the prices but for the purpose of this study it is assumed that each load is sold at the given price for that week. For the measurement of *n*, there were four different levels of *c* used in order to show how few or how many trades were needed at increasing allowances. The accuracy levels used were ±0.25, ±0.50, ±1.00, and ±1.50[3]. Franken and Parcell used ±0.25, ±0.35, and ±0.45,

[3] In the case of the cutout, *c* values were increased to $0.50, $1.00, $1.50, and $2.00 due to higher mean prices and the measure of *c*. See appendix Figure 18.

but due to the nature of the beef cattle market, increases/decreases of 10 cents was not representative of the spread between prices. **Table 1** and **Table 2** present the summary statistics for live and dressed cattle as well as the boxed beef cutout.

**Table 1** Summary Statistics for Weekly Steers and Heifers

| Live | Mean | Max | Min | SD |
|---|---|---|---|---|
| 5-Area | | | | |
| Head[1] | 71,232 | 194,534 | 11,400 | 33,334 |
| Weight[2] | 1,295 | 1,457 | 1,153 | 70 |
| Price[3] | 106.33 | 171.66 | 61.96 | 24 |
| Nebraska | | | | |
| Head | 15,847 | 42,613 | 1,327 | 6,435 |
| Weight | 1,342 | 1,508 | 1,178 | 61 |
| Price | 106.38 | 172.21 | 61.85 | 25 |
| Kansas | | | | |
| Head | 22,763 | 84,687 | 330 | 12,130 |
| Weight | 1,330 | 1,497 | 1,113 | 57 |
| Price | 172.83 | 172.83 | 61.87 | 24 |
| Iowa-Minnesota | | | | |
| Head | 7,794 | 26,496 | 72 | 4,229 |
| Weight | 1,357 | 1,519 | 1,197 | 104 |
| Price | 105.88 | 170.21 | 61.79 | 24 |
| Texas-Oklahoma-New Mexico | | | | |
| Head | 20,775 | 84,155 | 35 | 17,908 |
| Weight | 1,226 | 1,525 | 1,126 | 50 |
| Price | 106.31 | 173.00 | 61.98 | 24 |
| Colorado | | | | |
| Head | 4,545 | 18,379 | 200 | 2,802 |
| Weight | 1,305 | 1,527 | 1,159 | 67 |
| Price | 106.01 | 173.14 | 61.79 | 25 |
| Dressed | Max | Min | Mean | SD |
| 5-Area | | | | |
| Head[1] | 39,326 | 97,237 | 4,924 | 19,018 |
| Weight[2] | 846 | 952 | 751 | 41 |
| Price[3] | 168.69 | 270.35 | 97.63 | 39 |
| Nebraska | | | | |
| Head | 23,710 | 87,612 | 2,042 | 11,987 |
| Weight | 850 | 957 | 757 | 41 |
| Price | 168.79 | 270.65 | 97.27 | 39 |

[1] Weekly average head, =939 observations (2002 to 2019)
[2] Weekly average carcass weight (lbs.)
[3] Weekly average price ($/cwt)

**Table 2** Summary Statistics for Weekly National Beef Cutout

| | Mean | Max | Min | SD |
|---|---|---|---|---|
| Loads[1] | 816 | 2,024 | 110 | 363 |
| Price[2] | 178.85 | 261.04 | 121.44 | 36 |

[1] Weekly average loads, n=834 observations (2004 to 2019)
[2] Weekly average price ($/cwt)

The 5-Area market was also tested at three different levels of probability of 85%, 90%, and 95% in order to gauge how the probability influenced *n,* see **Figure 15**[4] in the appendix. In this figure, the black line is there to emphasize the difference in scale as the probability level goes up.

[4] All tables and graphs will be reported using a 90% probability unless otherwise stated

# Chapter 4 - Results

## 4.1 Measurement of Transactions Needed

### 4.11 Calculated Variance

As discussed before, live cattle and dressed are evaluated separately before they are combined to show the full market transactions at a given time. In **Error! Reference source not found.** the 5-Area market shows mean weekly transactions (actual transactions) versus needed transactions at four different accuracy levels. The two different transaction sizes are also compared here to show how different lot sizes can affect the years of sufficient and insufficient transactions[5]. At the $0.25 and $0.50 there are insufficient transactions in 2003 and in years between 2014 and 2017.

**Table 3** 5-Area Live Negotiated Transactions and Transactions Needed

| | | Mean Weekly | | | (P=90%, c= values in $/cwt) | | | |
|---|---|---|---|---|---|---|---|---|
| | Year | Head | Mean Weekly Transactions | Variance | ±0.25 | ±0.50 | ±1.00 | ±1.50 |
| 40 head per transaction | 2003 | 110,027 | **2,751** | 85.78 | 13,726 | 3,431 | 858 | 381 |
| | 2009 | 75,744 | **1,894** | 3.85 | 616 | 154 | 38 | 17 |
| | 2014 | 39,235 | **981** | 80.59 | 12,894 | 3,224 | 806 | 358 |
| | 2015 | 28,626 | **716** | 235.52 | 37,683 | 9,421 | 2,355 | 1,047 |
| | 2016 | 46,126 | **1,153** | 148.53 | 23,765 | 5,941 | 1,485 | 660 |
| 120 head per transaction | 2003 | 110,027 | **917** | 85.78 | 13,726 | 3,431 | 858 | 381 |
| | 2009 | 75,744 | **631** | 3.85 | 616 | 154 | 38 | 17 |
| | 2014 | 39,235 | **327** | 80.59 | 12,894 | 3,224 | 806 | 358 |
| | 2015 | 28,626 | **239** | 235.52 | 37,683 | 9,421 | 2,355 | 1,047 |
| | 2016 | 46,126 | **384** | 148.53 | 23,765 | 5,941 | 1,485 | 660 |

[5] For the remainder of the results, a transaction size of 40 will be used in order to be more concise. Realistically each region should have its own transaction size that best fits that individual market and it should change over time.

These spikes in the variance are caused by shocks to the market in 2003 with the BSE outbreak and the market crash around 2015. This method of calculating the variance only takes into account one market at a time and does not take into consideration if the price series are related to one another or that they are non-stationary. However, it is still valuable as it shows the impact that market shocks can have on each individual market. **Table 4** shows that the Nebraska live required transactions follow a similar trend to the 5-Area transactions. Nebraska is the market with largest share of cash negotiations out of the five regions and offers the most reliable pricing. Though the Texas region may have had more transactions leading up to 2011, Nebraska has been most consistent over time. In **Figure 17 Figure 16** of the appendix, actual transactions are compared to transactions needed at the $1.00 and $1.50 accuracy levels with a 90% probability. Though the BSE outbreak may have affected prices between 2003 and 2004 causing the variance to increase, transactions stayed relatively consistent and at the $1.50 accuracy level there are just enough actual transactions. During the market crash not only was there extreme price volatility but the number of transactions went down making the difference between actual and needed transactions more pronounced. At the end of 2018 it looked as if transactions were going to increase into 2019 however, that does not seem to be the case here. If market participants are okay with the lower levels of pricing accuracy, than there are sufficient transactions here.

**Table 4** Nebraska Live Negotiated Transactions and Transactions Needed

| | Mean Weekly | Mean Weekly | | (P=90%, c= values in $/cwt) | | | |
|---|---|---|---|---|---|---|---|
| Year | Head | Transactions | Variance | ±0.25 | ±0.50 | ±1.00 | ±1.50 |
| 2002 | 13,937 | 348 | 13.57 | 2,170 | 543 | 136 | 60 |
| 2003 | 19,553 | 489 | 102.05 | 16,327 | 4,082 | 1,020 | 454 |
| 2004 | 21,404 | 535 | 14.64 | 2,343 | 586 | 146 | 65 |
| 2005 | 18,747 | 469 | 21.54 | 3,446 | 861 | 215 | 96 |
| 2006 | 17,954 | 449 | 18.69 | 2,991 | 748 | 187 | 83 |
| 2007 | 16,936 | 423 | 13.96 | 2,234 | 558 | 140 | 62 |
| 2008 | 12,227 | 306 | 21.29 | 3,406 | 852 | 213 | 95 |
| 2009 | 13,297 | 332 | 5.03 | 805 | 201 | 50 | 22 |
| 2010 | 14,829 | 371 | 28.70 | 4,592 | 1,148 | 287 | 128 |
| 2011 | 14,160 | 354 | 42.09 | 6,734 | 1,684 | 421 | 187 |
| 2012 | 12,578 | 314 | 13.70 | 2,192 | 548 | 137 | 61 |
| 2013 | 11,102 | 278 | 14.50 | 2,320 | 580 | 145 | 64 |
| 2014 | 16,549 | 414 | 79.50 | 12,720 | 3,180 | 795 | 353 |
| 2015 | 10,407 | 260 | 237.32 | 37,971 | 9,493 | 2,373 | 1,055 |
| 2016 | 16,201 | 405 | 149.68 | 23,949 | 5,987 | 1,497 | 665 |
| 2017 | 19,877 | 497 | 83.06 | 13,290 | 3,322 | 831 | 369 |
| 2018 | 22,317 | 558 | 43.66 | 6,986 | 1,746 | 437 | 194 |
| 2019 | 12,845 | 321 | 62.37 | 9,980 | 2,495 | 624 | 277 |

sufficient transactions in all but 2015 and 2016. However, lowering the standard does not make the issue of market thinness go away, the pricing accuracy could be ± $5.00/cwt but that would be completely unrealistic in terms of actual market conditions. Although Kansas has decreased their participation in the cash market, they still have more transactions than both Texas and Colorado. The variance in Kansas also seems to be slightly lower than in Nebraska for all years except 2019 as seen in **Table 5**. This may be due to the fact that several large packers are surrounded by large feedyards especially in Southwest Kansas. Decreased transportation costs create a more efficient market and makes price discovery less expensive.

**Table 5** Kansas Live Negotiated Transactions and Transactions Needed

| | Mean Weekly | Mean Weekly | | (P=90%, c= values in $/cwt) | | | |
|---|---|---|---|---|---|---|---|
| Year | Head | Transactions | Variance | ±0.25 | ±0.50 | ±1.00 | ±1.50 |
| 2002 | 29,842 | 746 | 13.17 | 2,107 | 527 | 132 | 59 |
| 2003 | 38,832 | 971 | 82.83 | 13,253 | 3,313 | 828 | 368 |
| 2004 | 36,608 | 915 | 14.74 | 2,359 | 590 | 147 | 66 |
| 2005 | 33,697 | 842 | 18.82 | 3,011 | 753 | 188 | 84 |
| 2006 | 30,715 | 768 | 21.72 | 3,475 | 869 | 217 | 97 |
| 2007 | 27,998 | 700 | 10.96 | 1,753 | 438 | 110 | 49 |
| 2008 | 24,469 | 612 | 20.00 | 3,199 | 800 | 200 | 89 |
| 2009 | 25,458 | 636 | 3.87 | 619 | 155 | 39 | 17 |
| 2010 | 30,124 | 753 | 23.98 | 3,837 | 959 | 240 | 107 |
| 2011 | 26,631 | 666 | 37.33 | 5,972 | 1,493 | 373 | 166 |
| 2012 | 17,972 | 449 | 14.84 | 2,375 | 594 | 148 | 66 |
| 2013 | 12,699 | 317 | 16.06 | 2,570 | 643 | 161 | 71 |
| 2014 | 8,526 | 213 | 92.51 | 14,802 | 3,701 | 925 | 411 |
| 2015 | 6,424 | 161 | 217.36 | 34,778 | 8,695 | 2,174 | 966 |
| 2016 | 16,551 | 414 | 147.20 | 23,552 | 5,888 | 1,472 | 654 |
| 2017 | 16,159 | 404 | 80.93 | 12,949 | 3,237 | 809 | 360 |
| 2018 | 14,452 | 361 | 42.46 | 6,793 | 1,698 | 425 | 189 |
| 2019 | 12,067 | 302 | 68.76 | 11,001 | 2,750 | 688 | 306 |

**Table 6** Iowa-Minnesota Live Negotiated Transactions and Transactions Needed

| | Mean Weekly | Mean Weekly | | (P=90%, c= values in $/cwt) | | | |
|---|---|---|---|---|---|---|---|
| Year | Head | Transactions | Variance | ±0.50 | ±1.00 | ±1.50 | ±2.00 |
| 2002 | 4,119 | 103 | 12.98 | 519 | 130 | 58 | 32 |
| 2003 | 6,380 | 160 | 105.96 | 4,238 | 1,060 | 471 | 265 |
| 2004 | 7,806 | 195 | 13.27 | 531 | 133 | 59 | 33 |
| 2005 | 6,517 | 163 | 21.86 | 874 | 219 | 97 | 55 |
| 2006 | 6,973 | 174 | 16.22 | 649 | 162 | 72 | 41 |
| 2007 | 9,136 | 228 | 14.01 | 560 | 140 | 62 | 35 |
| 2008 | 6,271 | 157 | 20.05 | 802 | 200 | 89 | 50 |
| 2009 | 6,715 | 168 | 5.33 | 213 | 53 | 24 | 13 |
| 2010 | 8,288 | 207 | 25.57 | 1,023 | 256 | 114 | 64 |
| 2011 | 9,025 | 226 | 41.02 | 1,641 | 410 | 182 | 103 |
| 2012 | 8,918 | 223 | 12.96 | 518 | 130 | 58 | 32 |
| 2013 | 6,601 | 165 | 11.62 | 465 | 116 | 52 | 29 |
| 2014 | 9,819 | 245 | 74.28 | 2,971 | 743 | 330 | 186 |
| 2015 | 8,486 | 212 | 259.70 | 10,388 | 2,597 | 1,154 | 649 |
| 2016 | 5,949 | 149 | 149.16 | 5,966 | 1,492 | 663 | 373 |
| 2017 | 7,736 | 193 | 81.44 | 3,258 | 814 | 362 | 204 |
| 2018 | 11,505 | 288 | 48.59 | 1,944 | 486 | 216 | 121 |
| 2019 | 9,973 | 249 | 61.28 | 2,451 | 613 | 272 | 153 |

The Iowa-Minnesota market is the only market that seems to be increasing cash negotiations rather than decreasing. In **Table 6**, there are clearly fewer transactions than in other regions, but this does not necessarily mean that price discovery is not occurring, for this market there are overall less cattle, unlike Texas which has more cattle than any other region. The pricing accuracy is widened for Iowa to account for the differences in this market. The 5-Area dressed market has had fewer negotiated cash transactions, but more and more cattle are being sold on a dressed basis as shown in **Figure 1**. Although the trends in live and dressed are similar, the variance is significantly larger from 2014 on. For the dressed market, it is unlikely that price discovery will increase to the level of the live market again. Most studies have looked at the live and dressed markets together, either by putting the dressed in terms of live or vice versa, it is important though to look at them separately as well in order to fully understand what is going on in each market and where issues of market thinness are most prevalent.

**Table 7** 5-Area Dressed Negotiated Transactions and Transactions Needed

| | Mean Weekly | Mean Weekly | | (P=90%, c= values in $/cwt) | | | |
|---|---|---|---|---|---|---|---|
| Year | Head | Transactions | Variance | ±0.50 | ±1.00 | ±1.50 | ±2.00 |
| 2002 | 55,469 | 2,201 | 35.28 | 5,645 | 1,411 | 353 | 157 |
| 2003 | 46,848 | 1,859 | 241.99 | 38,719 | 9,680 | 2,420 | 1,076 |
| 2004 | 52,339 | 2,077 | 34.16 | 5,465 | 1,366 | 342 | 152 |
| 2005 | 61,101 | 2,425 | 62.25 | 9,960 | 2,490 | 623 | 277 |
| 2006 | 59,161 | 2,348 | 47.99 | 7,678 | 1,920 | 480 | 213 |
| 2007 | 57,735 | 2,291 | 37.77 | 6,044 | 1,511 | 378 | 168 |
| 2008 | 61,362 | 2,435 | 46.41 | 7,425 | 1,856 | 464 | 206 |
| 2009 | 51,928 | 2,061 | 11.46 | 1,833 | 458 | 115 | 51 |
| 2010 | 44,353 | 1,760 | 58.38 | 9,341 | 2,335 | 584 | 259 |
| 2011 | 36,132 | 1,434 | 94.33 | 15,092 | 3,773 | 943 | 419 |
| 2012 | 26,972 | 1,070 | 36.23 | 5,796 | 1,449 | 362 | 161 |
| 2013 | 25,265 | 1,003 | 29.45 | 4,712 | 1,178 | 295 | 131 |
| 2014 | 19,708 | 782 | 157.65 | 25,224 | 6,306 | 1,577 | 701 |
| 2015 | 21,747 | 863 | 651.73 | 104,276 | 26,069 | 6,517 | 2,897 |
| 2016 | 25,231 | 1,001 | 392.24 | 62,759 | 15,690 | 3,922 | 1,743 |
| 2017 | 20,709 | 822 | 219.59 | 35,135 | 8,784 | 2,196 | 976 |
| 2018 | 21,393 | 849 | 120.66 | 19,305 | 4,826 | 1,207 | 536 |
| 2019 | 19,827 | 787 | 167.76 | 26,842 | 6,710 | 1,678 | 746 |

In the case of the Nebraska dressed transactions, there is more price discovery occurring in this market leading up to 2014.

**Table 8** Nebraska Dressed Negotiated Transactions and Transactions Needed

| | Mean Weekly | Mean Weekly | | (P=90%, c= values in $/cwt) | | | |
|---|---|---|---|---|---|---|---|
| Year | Head | Transactions | Variance | ±0.50 | ±1.00 | ±1.50 | ±2.00 |
| 2002 | 33,025 | 669 | 35.73 | 2,858 | 715 | 318 | 179 |
| 2003 | 30,475 | 601 | 245.09 | 19,607 | 4,902 | 2,179 | 1,225 |
| 2004 | 33,445 | 666 | 35.42 | 2,833 | 708 | 315 | 177 |
| 2005 | 33,525 | 675 | 65.72 | 5,257 | 1,314 | 584 | 329 |
| 2006 | 34,652 | 711 | 50.07 | 4,006 | 1,001 | 445 | 250 |
| 2007 | 34,292 | 698 | 40.85 | 3,268 | 817 | 363 | 204 |
| 2008 | 36,437 | 751 | 47.03 | 3,763 | 941 | 418 | 235 |
| 2009 | 31,731 | 677 | 12.46 | 996 | 249 | 111 | 62 |
| 2010 | 28,651 | 603 | 58.07 | 4,645 | 1,161 | 516 | 290 |
| 2011 | 23,595 | 501 | 94.72 | 7,578 | 1,894 | 842 | 474 |
| 2012 | 17,198 | 376 | 37.08 | 2,966 | 742 | 330 | 185 |
| 2013 | 15,368 | 332 | 27.37 | 2,190 | 547 | 243 | 137 |
| 2014 | 11,654 | 258 | 156.64 | 12,531 | 3,133 | 1,392 | 783 |
| 2015 | 12,409 | 280 | 655.65 | 52,452 | 13,113 | 5,828 | 3,278 |
| 2016 | 14,932 | 332 | 387.75 | 31,020 | 7,755 | 3,447 | 1,939 |
| 2017 | 12,097 | 267 | 218.71 | 17,496 | 4,374 | 1,944 | 1,094 |
| 2018 | 11,851 | 264 | 117.93 | 9,435 | 2,359 | 1,048 | 590 |
| 2019 | 11,107 | 246 | 169.81 | 13,585 | 3,396 | 1,509 | 849 |

Nebraska is the only dressed market reported here because in the other regions there are too many weeks without any cash negotiations after 2014. These gaps are a signal, in and of themselves, that cattle sold on a dressed basis in the cash market have declined significantly over the past five years. **Table 9** shows the combined live and dressed transactions. With both live and dressed there are fewer years with insufficient transactions, especially at the $1.00 and $1.50 accuracy levels.

**Table 9** 5-Area Live and Dressed Negotiated Transactions and Transactions Needed[6]

| | Mean Weekly | Mean Weekly | | (P=90%, c= values in $/cwt) | | | |
|---|---|---|---|---|---|---|---|
| Year | Head | Transactions | Variance | ±0.25 | ±0.50 | ±1.00 | ±1.50 |
| 2002 | 90,249 | 3,345 | 13.07 | 2,091 | 523 | 131 | 58 |
| 2003 | 110,027 | 3,286 | 85.78 | 13,726 | 3,431 | 858 | 381 |
| 2004 | 115,779 | 3,469 | 14.44 | 2,310 | 577 | 144 | 64 |
| 2005 | 109,978 | 3,346 | 19.24 | 3,079 | 770 | 192 | 86 |
| 2006 | 101,855 | 3,149 | 19.85 | 3,177 | 794 | 199 | 88 |
| 2007 | 95,117 | 2,956 | 11.38 | 1,821 | 455 | 114 | 51 |
| 2008 | 79,216 | 2,474 | 19.66 | 3,145 | 786 | 197 | 87 |
| 2009 | 75,744 | 2,410 | 3.85 | 616 | 154 | 38 | 17 |
| 2010 | 78,386 | 2,472 | 24.85 | 3,976 | 994 | 248 | 110 |
| 2011 | 70,380 | 2,231 | 38.87 | 6,220 | 1,555 | 389 | 173 |
| 2012 | 51,515 | 1,664 | 14.13 | 2,261 | 565 | 141 | 63 |
| 2013 | 37,715 | 1,168 | 14.75 | 2,360 | 590 | 148 | 66 |
| 2014 | 39,235 | 1,305 | 81.01 | 12,962 | 3,241 | 810 | 360 |
| 2015 | 28,626 | 977 | 234.82 | 37,571 | 9,393 | 2,348 | 1,044 |
| 2016 | 46,126 | 1,575 | 148.27 | 23,723 | 5,931 | 1,483 | 659 |
| 2017 | 54,841 | 1,841 | 80.93 | 12,949 | 3,237 | 809 | 360 |
| 2018 | 56,032 | 1,896 | 43.70 | 6,993 | 1,748 | 437 | 194 |
| 2019 | 39,519 | 988 | 63.45 | 10,152 | 2,538 | 635 | 282 |

**Table 10** shows that leading up to 2013 and during 2018 there were sufficient transactions in the market. LMIC only provides data for the beef cutout from 2004 on, and between that time and 2019 there has been a steady decrease in cash negotiated transactions. The pricing accuracy has changed for this series due to the higher mean prices, in the section on solving for the pricing accuracy, these ranges better fit the market than the ranges used for the live or dressed markets. As discussed previously the beef cutout does not include any export or branded beef prices and volumes. By excluding these transactions and prices the cutout is missing out on a significant proportion of the beef being sold. Producers try to gain the premiums that come with prime, choice, and branding such as CAB which creates higher quality beef in the market overall, but there are serious draw backs when it comes to price discovery.

[6] Live and dressed transactions were combined by putting dressed transactions in terms of live weights and prices using a 63% dressing percentage. Transportation cost was accounted for by subtracting $0.50 from the dressed price.

**Table 10** Boxed Beef Cutout Negotiated Transactions and Transactions Needed

| Year | Mean Weekly Transactions | Variance | (P=90%, c= values in $/cwt) ±0.50 | ±1.00 | ±1.50 | ±2.00 |
|---|---|---|---|---|---|---|
| 2004 | 1325 | 53.73 | 2149 | 537 | 239 | 134 |
| 2005 | 1374 | 74.27 | 2971 | 743 | 330 | 186 |
| 2006 | 1292 | 20.85 | 834 | 208 | 93 | 52 |
| 2007 | 1218 | 53.48 | 2139 | 535 | 238 | 134 |
| 2008 | 1030 | 67.26 | 2691 | 673 | 299 | 168 |
| 2009 | 963 | 19.76 | 790 | 198 | 88 | 49 |
| 2010 | 814 | 66.58 | 2663 | 666 | 296 | 166 |
| 2011 | 811 | 39.37 | 1575 | 394 | 175 | 98 |
| 2012 | 720 | 22.31 | 893 | 223 | 99 | 56 |
| 2013 | 601 | 27.00 | 1080 | 270 | 120 | 68 |
| 2014 | 565 | 184.34 | 7374 | 1843 | 819 | 461 |
| 2015 | 518 | 393.74 | 15750 | 3937 | 1750 | 984 |
| 2016 | 493 | 263.35 | 10534 | 2634 | 1170 | 658 |
| 2017 | 467 | 231.50 | 9260 | 2315 | 1029 | 579 |
| 2018 | 434 | 43.09 | 1724 | 431 | 192 | 108 |
| 2019 | 433 | 156.84 | 6274 | 1568 | 697 | 392 |

### 4.12 1st Differences

In order to measure how the regional markets interact with each other, a first differences measure of the variance is used. Using Ordinary Least Squares (OLS) regressions, the individual price series was regressed for the year and then the 1st difference variables were regressed for the year using the following equation

$$(3)\ y_t - y_{t-1} = \mu + \beta(x_t - x_{t-1}) + v_t.$$

The estimated variance is equal to the sum of squared errors of μ. The regression was estimated for each year. As explained by Tomek, for each region, "the appropriate $\sigma^2$ relates to the changes in price differences" between one region and another Franken and Parcell compare the Iowa-Minnesota market to the St. Joseph markets and for this thesis, five markets pairs are compared to get the estimated variance for each region. The five pairs are shown in **Table 11**.

**Table 11** 1st Difference Pairs for Estimated Variance

| | |
|---|---|
| Kansas | Nebraska |
| Nebraska | Kansas |
| Nebraska | Iowa-Minnesota |
| Nebraska | Texas-Oklahoma-New Mexico |
| Nebraska | Colorado |

In the following tables the calculated variance that was used in the previous section is compared with the 1st difference estimation. In Table 12, the Nebraska variance is obtained by 1st differencing it with the Kansas prices. The probability and accuracy level for all reported tables is set at 90% and $1.50/cwt. The estimated variance instead of responding to market shocks, goes up or down based on how different the two price series are to each other. Between 2002 and 2014, the calculated and estimated variances follow the same trend. However, as shown in

**Figure 5**, during the market crash the Kansas and Nebraska prices converge causing the required transactions to go down rather than up. By using the 1st differences estimation of the variance there are only insufficient transactions, at 90% probability and $1.50/cwt accuracy level, during 2003.

**Table 12** 1st Difference Nebraska Live Negotiated Transactions and Needed Transactions

| | | | | (p=90%, c= ±$1.50/cwt) | |
|---|---|---|---|---|---|
| Year | Mean Weekly Transactions | Calculated Variance | Variance in 1st Differences | Calculated Needed | 1st Difference Needed |
| 2002 | 348 | 13.57 | 9.99 | 60 | 44 |
| 2003 | 489 | 102.05 | 123.02 | 454 | 547 |
| 2004 | 535 | 14.64 | 82.26 | 65 | 366 |
| 2005 | 469 | 21.54 | 30.27 | 96 | 135 |
| 2006 | 449 | 18.69 | 35.83 | 83 | 159 |
| 2007 | 423 | 13.96 | 23.49 | 62 | 104 |
| 2008 | 306 | 21.29 | 23.39 | 95 | 104 |
| 2009 | 332 | 5.03 | 14.56 | 22 | 65 |
| 2010 | 371 | 28.70 | 22.98 | 128 | 102 |
| 2011 | 354 | 42.09 | 49.83 | 187 | 221 |
| 2012 | 314 | 13.70 | 17.33 | 61 | 77 |
| 2013 | 278 | 14.50 | 17.78 | 64 | 79 |
| 2014 | 414 | 79.50 | 74.67 | 353 | 332 |
| 2015 | 260 | 237.32 | 57.05 | 1,055 | 254 |
| 2016 | 405 | 149.68 | 82.69 | 665 | 367 |
| 2017 | 497 | 83.06 | 65.49 | 369 | 291 |
| 2018 | 558 | 43.66 | 63.68 | 194 | 283 |
| 2019 | 321 | 62.37 | 47.30 | 277 | 210 |

**Figure 5**

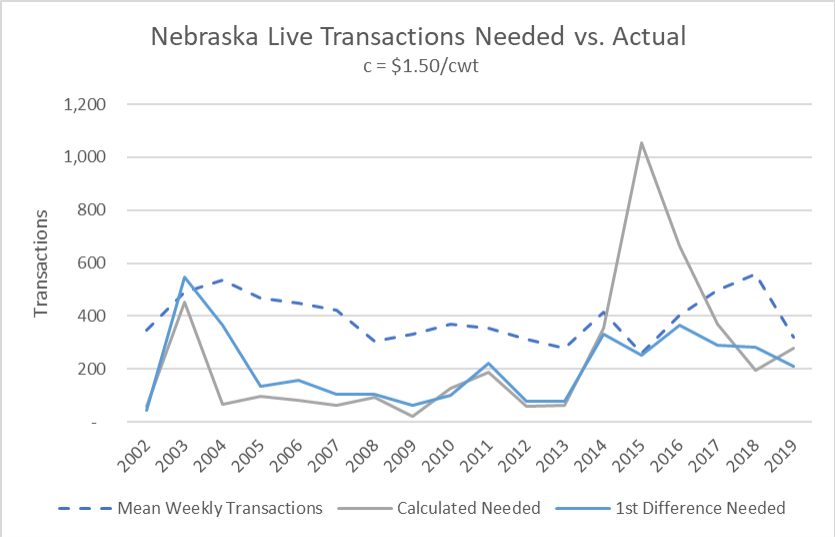


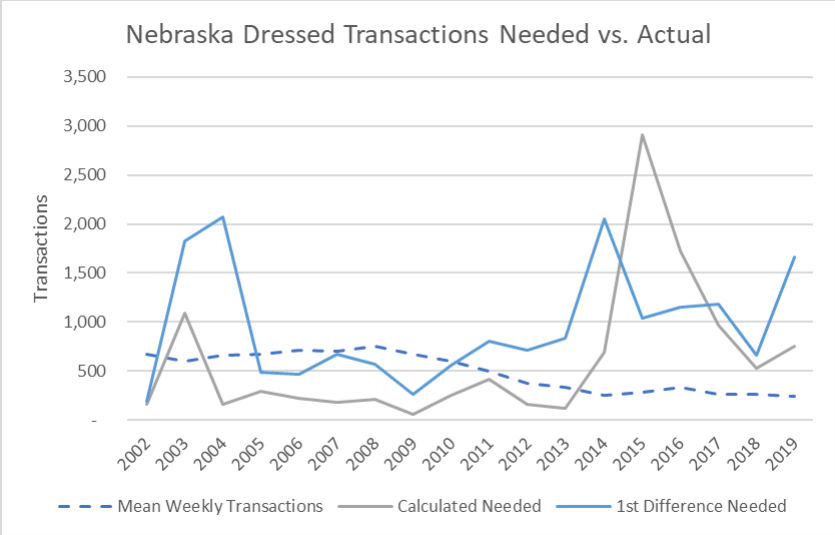

**Table 13** 1st Difference Nebraska Dressed Negotiated Transactions and Needed Transactions

| | | | | (p=90%, c= ±$1.50/cwt) | |
|---|---|---|---|---|---|
| Year | Mean Weekly Transactions | Calculated Variance | Variance in 1st Differences | Calculated Needed | 1st Difference Needed |
| 2002 | 669 | 35.73 | 42.07 | 159 | 187 |
| 2003 | 601 | 245.09 | 410.93 | 1,089 | 1,826 |
| 2004 | 666 | 35.42 | 466.65 | 157 | 2,074 |
| 2005 | 675 | 65.72 | 109.45 | 292 | 486 |
| 2006 | 711 | 50.07 | 105.88 | 223 | 471 |
| 2007 | 698 | 40.85 | 152.04 | 182 | 676 |
| 2008 | 751 | 47.03 | 128.36 | 209 | 570 |
| 2009 | 677 | 12.46 | 60.17 | 55 | 267 |
| 2010 | 603 | 58.07 | 125.94 | 258 | 560 |
| 2011 | 501 | 94.72 | 182.27 | 421 | 810 |
| 2012 | 376 | 37.08 | 160.95 | 165 | 715 |
| 2013 | 332 | 27.37 | 188.80 | 122 | 839 |
| 2014 | 258 | 156.64 | 461.15 | 696 | 2,050 |
| 2015 | 280 | 655.65 | 234.54 | 2,914 | 1,042 |
| 2016 | 332 | 387.75 | 258.67 | 1,723 | 1,150 |
| 2017 | 267 | 218.71 | 265.56 | 972 | 1,180 |
| 2018 | 264 | 117.93 | 149.03 | 524 | 662 |
| 2019 | 246 | 169.81 | 375.35 | 755 | 1,668 |

**Table 13** provides results that were not expected based on previous measures. As in the live estimation the Nebraska prices are paired with the Kansas prices, the main reason for this pairing

was that the Kansas market had less weeks with no transactions[7]. The estimated variance is much larger than the calculated variance and as shown in **Figure 6**[8] during the BSE outbreak. It is also interesting here how different the dressed market looks from the live market above, there may be times when these markets do not respond the same to shocks in the market.

**Figure 6**




For **Table 14**, Kansas prices were differenced against Nebraska prices in order to get the estimated variance. The trend in the Kansas market is similar to that in the Nebraska save the period between 2003 and 2004, where transactions needed stay at 500 transactions rather than coming back down in 2004. **Figure 17** in the appendix shows all of the regions not reported in the main body.

[7] The few weeks that were missing were filled in by using the prices from the Kansas live prices and adjusted using a 63% dressing percentage.

[8] *c* is equal to $1.50/cwt for all figures comparing the estimated and calculated variances.

**Table 14** 1st Difference Kansas Live Negotiated Transactions and Needed Transactions

| | | | | (p=90%, c= ±$1.50/cwt) | |
|---|---|---|---|---|---|
| Year | Mean Weekly Transactions | Calculated Variance | Variance in 1st Differences | Calculated Needed | 1st Difference Needed |
| 2002 | 746 | 13.17 | 9.30 | 59 | 41 |
| 2003 | 971 | 82.83 | 109.26 | 368 | 486 |
| 2004 | 915 | 14.74 | 111.47 | 66 | 495 |
| 2005 | 842 | 18.82 | 35.89 | 84 | 160 |
| 2006 | 768 | 21.72 | 37.27 | 97 | 166 |
| 2007 | 700 | 10.96 | 29.12 | 49 | 129 |
| 2008 | 612 | 20.00 | 20.03 | 89 | 89 |
| 2009 | 636 | 3.87 | 14.63 | 17 | 65 |
| 2010 | 753 | 23.98 | 20.83 | 107 | 93 |
| 2011 | 666 | 37.33 | 52.04 | 166 | 231 |
| 2012 | 449 | 14.84 | 18.93 | 66 | 84 |
| 2013 | 317 | 16.06 | 24.15 | 71 | 107 |
| 2014 | 213 | 92.51 | 67.51 | 411 | 300 |
| 2015 | 161 | 217.36 | 59.99 | 966 | 267 |
| 2016 | 414 | 147.20 | 77.36 | 654 | 344 |
| 2017 | 404 | 80.93 | 64.32 | 360 | 286 |
| 2018 | 361 | 42.46 | 62.18 | 189 | 276 |
| 2019 | 302 | 68.76 | 61.34 | 306 | 273 |

The Iowa-Minnesota estimated variance is very interesting in that it does not really spike at any point. Since it is compared to Nebraska prices there seems to be a very close relationship between these two price series. This case in particular proves why the variance is so important in this method because depending on how it is measured, the results can be very different.

**Table 15** 1st Difference Iowa-Minnesota Live Negotiated Transactions and Needed Transactions

| | | | | (p=90%, c= ±1.50) | |
|---|---|---|---|---|---|
| Year | Mean Weekly Transactions | Calculated Variance | Variance in 1st Differences | Calculated Needed | 1st Difference Needed |
| 2002 | 103 | 12.98 | 9.04 | 58 | 40 |
| 2003 | 160 | 105.96 | 31.98 | 471 | 142 |
| 2004 | 195 | 13.27 | 30.13 | 59 | 134 |
| 2005 | 163 | 21.86 | 22.51 | 97 | 100 |
| 2006 | 174 | 16.22 | 29.30 | 72 | 130 |
| 2007 | 228 | 14.01 | 30.64 | 62 | 136 |
| 2008 | 157 | 20.05 | 30.49 | 89 | 136 |
| 2009 | 168 | 5.33 | 25.37 | 24 | 113 |
| 2010 | 207 | 25.57 | 16.15 | 114 | 72 |
| 2011 | 226 | 41.02 | 38.61 | 182 | 172 |
| 2012 | 223 | 12.96 | 41.32 | 58 | 184 |
| 2013 | 165 | 11.62 | 40.56 | 52 | 180 |
| 2014 | 245 | 74.28 | 47.45 | 330 | 211 |
| 2015 | 212 | 259.70 | 39.54 | 1,154 | 176 |
| 2016 | 149 | 149.16 | 69.39 | 663 | 308 |
| 2017 | 193 | 81.44 | 74.14 | 362 | 330 |
| 2018 | 288 | 48.59 | 68.90 | 216 | 306 |
| 2019 | 249 | 61.28 | 46.99 | 272 | 209 |

For Texas, only data through 2018 was used due to several weeks of no transactions during 2019.

**Table 16** 1st Difference Texas-Oklahoma-New Mexico Live Negotiated Transactions and Needed Transactions

| | | | | (p=90%, c= ±1.50) | |
|---|---|---|---|---|---|
| Year | Mean Weekly Transactions | Calculated Variance | Variance in 1st Differences | Calculated Needed | 1st Difference Needed |
| 2002 | 951 | 12.87 | 10.27 | 57 | 46 |
| 2003 | 1,032 | 78.64 | 48.09 | 350 | 214 |
| 2004 | 1,109 | 14.91 | 42.77 | 66 | 190 |
| 2005 | 1,102 | 18.54 | 43.43 | 82 | 193 |
| 2006 | 953 | 21.52 | 42.73 | 96 | 190 |
| 2007 | 872 | 10.05 | 32.79 | 45 | 146 |
| 2008 | 782 | 19.83 | 24.43 | 88 | 109 |
| 2009 | 628 | 3.71 | 13.84 | 16 | 62 |
| 2010 | 508 | 23.81 | 19.94 | 106 | 89 |
| 2011 | 406 | 36.30 | 55.47 | 161 | 247 |
| 2012 | 217 | 16.04 | 31.42 | 71 | 140 |
| 2013 | 121 | 16.95 | 30.86 | 75 | 137 |
| 2014 | 49 | 91.90 | 94.11 | 408 | 418 |
| 2015 | 36 | 217.25 | 97.27 | 966 | 432 |
| 2016 | 104 | 147.77 | 62.27 | 657 | 277 |
| 2017 | 160 | 82.17 | 53.71 | 365 | 239 |
| 2018 | 117 | 40.84 | 79.46 | 182 | 353 |

Similar to Iowa, Texas prices seem to within the same range as the Nebraska market, though there is more of a response during the market crash around 2015. This result was expected since price discovery in Texas has decreased significantly since 2005 and it is presumed that those marketing cattle within the Texas region are marketing them based off of the Nebraska prices.

**Table 17** 1st Difference Colorado Live Negotiated Transactions and Needed Transactions

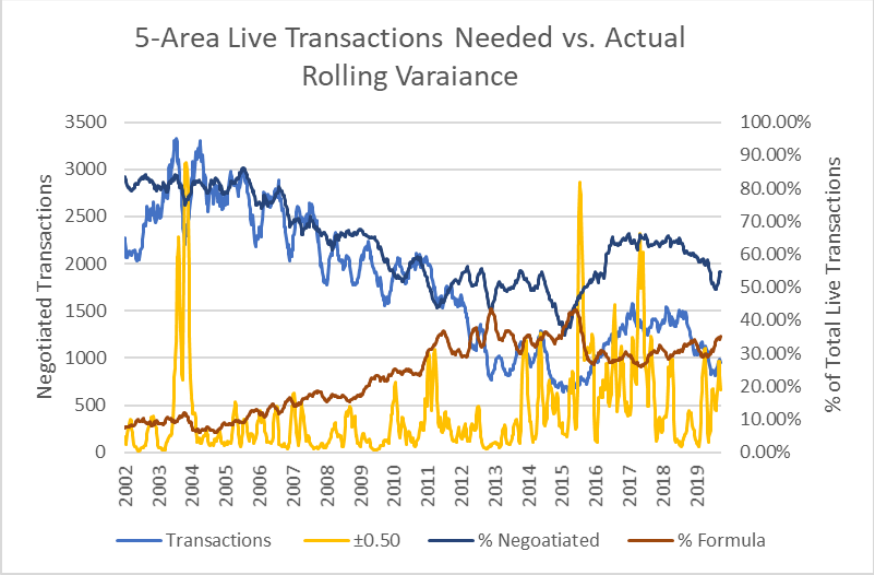
| | | | | (p=90%, c= ±1.50) | |
|---|---|---|---|---|---|
| Year | Mean Weekly Transactions | Calculated Variance | Variance in 1st Differences | Calculated Needed | 1st Difference Needed |
| 2002 | 109 | 13.46 | 9.33 | 34 | 23 |
| 2003 | 157 | 95.38 | 37.45 | 238 | 94 |
| 2004 | 140 | 15.23 | 18.55 | 38 | 46 |
| 2005 | 165 | 20.49 | 13.97 | 51 | 35 |
| 2006 | 194 | 19.55 | 11.63 | 49 | 29 |
| 2007 | 153 | 13.74 | 17.64 | 34 | 44 |
| 2008 | 123 | 21.56 | 13.51 | 54 | 34 |
| 2009 | 131 | 4.46 | 12.78 | 11 | 32 |
| 2010 | 116 | 27.61 | 10.86 | 69 | 27 |
| 2011 | 107 | 42.59 | 11.18 | 106 | 28 |
| 2012 | 85 | 14.42 | 20.17 | 36 | 50 |
| 2013 | 62 | 16.79 | 13.82 | 42 | 35 |
| 2014 | 60 | 85.67 | 20.99 | 214 | 52 |
| 2015 | 40 | 233.43 | 58.72 | 584 | 147 |
| 2016 | 82 | 143.84 | 75.38 | 360 | 188 |
| 2017 | 116 | 81.97 | 95.99 | 205 | 240 |

Colorado is only reported from 2002 to 2017 due to a significant lack of transactions during 2018 and 2019. The Colorado prices are very close to the Nebraska prices and this was expected considering that the market in Colorado has been thinning since the 60's when Tomek first used Chebyshev's inequality. However, after the market crash Colorado diverges from the Nebraska market.

### 4.13 Rolling Variance

The last measurement of the variance was calculated using a quarterly rolling variance. As mentioned before, the rolling variance allows us to see what is occurring week to week instead of just getting one snapshot for the year. All the same accuracy levels were used as in the previous variance measurements. Figure 7 shows the actual and needed transactions along with the % share of cash negotiations and formula trades.

**Figure 7**




The percentages are added to show how changes in the % share of each marketing method follow both actual transactions and needed. Figure 8 shows the same as Figure 7 except for dressed cattle. The difference between % negotiated transactions and % formula in dressed transactions is almost opposite of % shares in live transactions. There are times between 2013 and 2017 that there are insufficient transactions even at $1.00 level of accuracy however, even during this time period there are still week where cash negotiations increase and actual transactions exceed needed transactions.

**Figure 8**

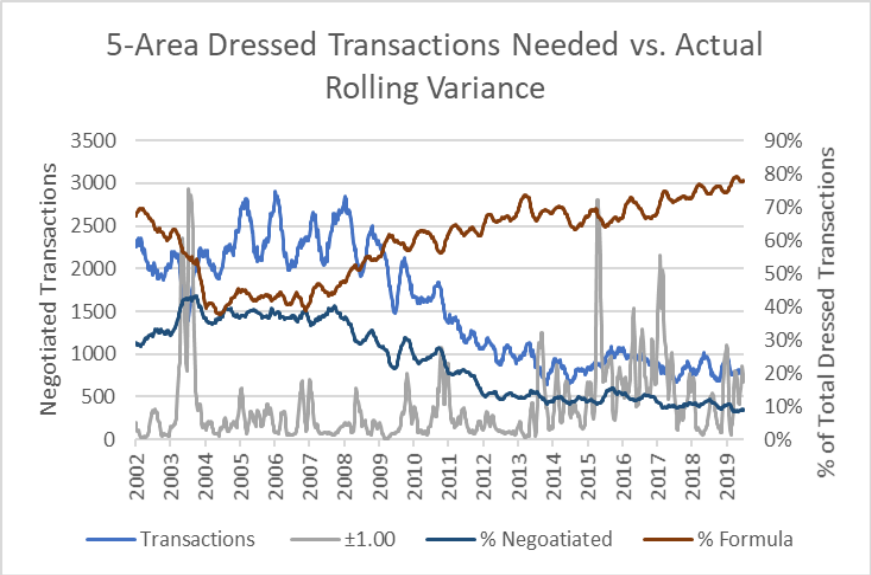
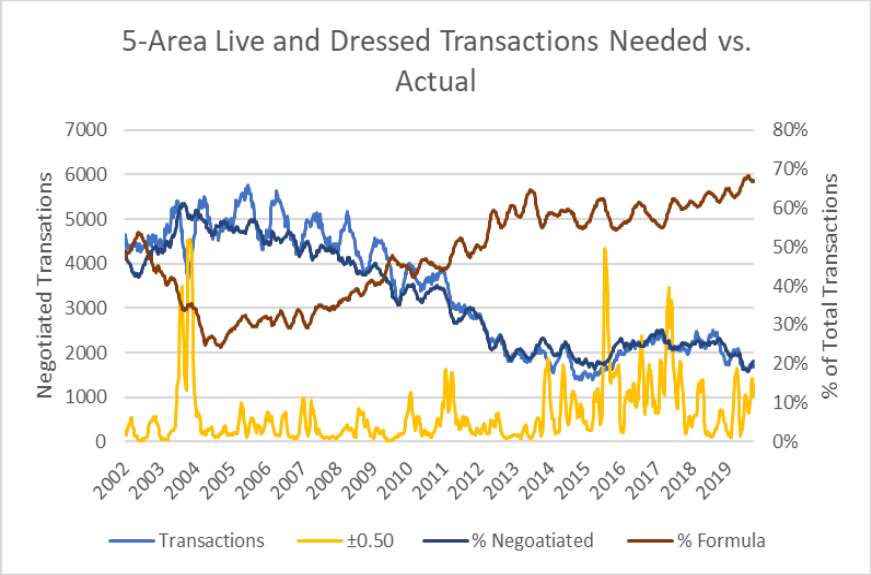


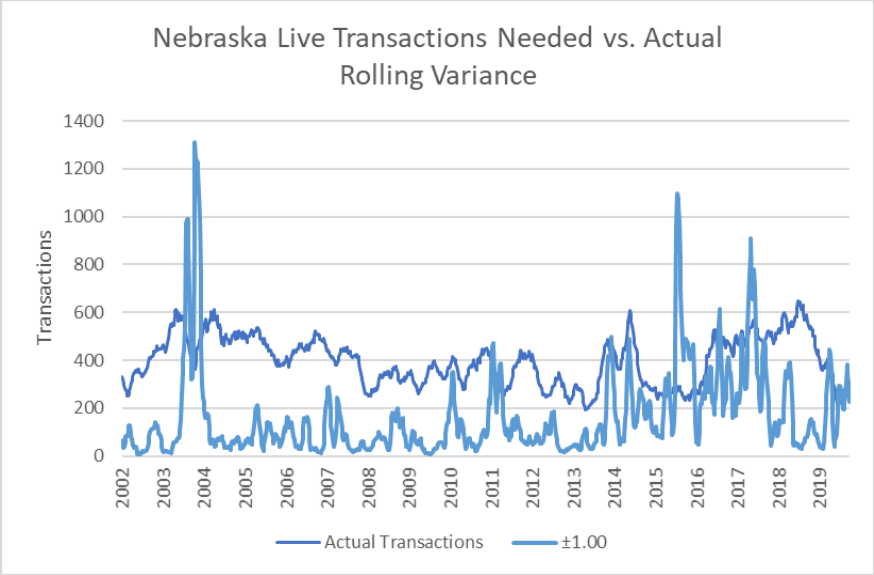

Figure 9 combines both live and dressed transactions and it appears that there are sufficient transactions is most weeks. Instead of saying there are not enough transactions in all of 2003, it is clear that this is only isolated to a couple of weeks between December of 2003 and January of 2004. The same goes for the market crash; there were several weeks between 2015 and 2017 that did have sufficient transactions for accurate price discovery, but the large spikes in

**Figure 9**



the price variance causes the yearly data to assume that the whole year had insufficient transactions. This method of measuring the variance is the clearest when there is a lack of price discovery. For Nebraska live cattle transactions in Figure 10, it is more clear how this individual region looks week to week. The main shocks that have been discussed have been the BSE outbreak and the time between 2014 and 2017 however, it is clearer in this figure that these where not the only times when there may not have been sufficient transactions, such as 2011. The shocks may look more dramatic here but outside of the times of extreme volatility this market shows that there is still price discovery occurring.

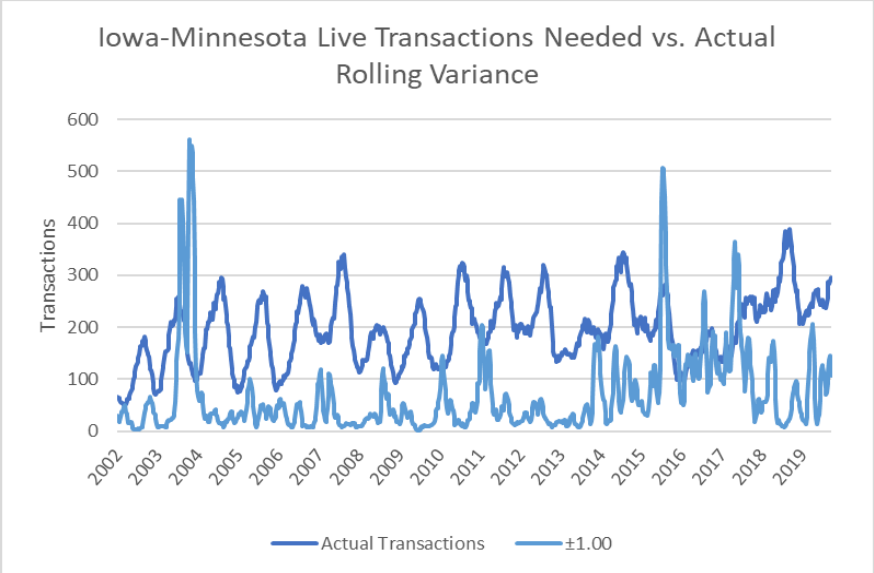
**Figure 10**




In Iowa-Minnesota there seems to be a cyclical pattern to the actual transactions that is more consistent than the Nebraska market or the 5-Area market. Although this market is smaller compared to the Nebraska, Kansas, or Texas markets, price discovery is increasing which is not the case for these other markets. By isolating certain weeks, it is easier to determine when insufficient transactions are due to market shocks or if price discovery is simply not happening. When looking at the graphs in Figure 15 and Figure 16 in the appendix, it is impossible to

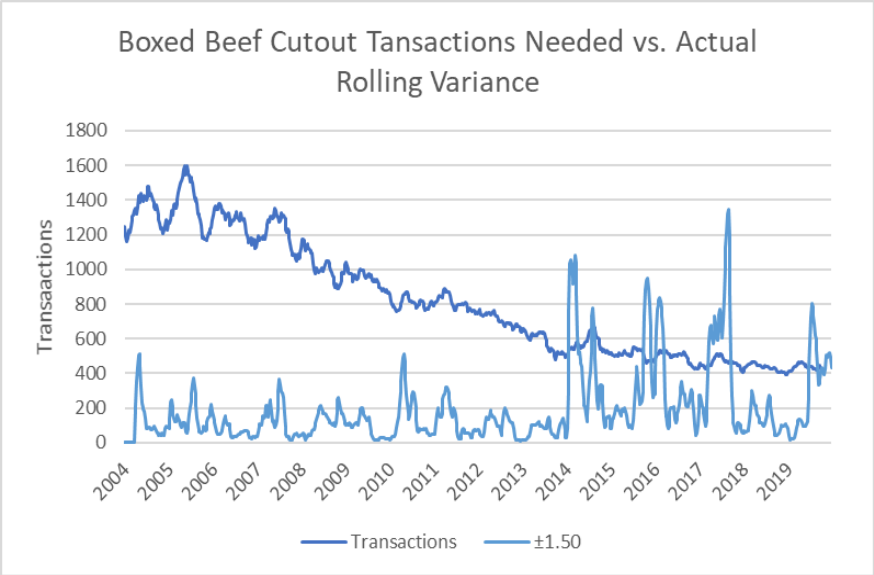
determine when certain shocks occur during the year or when the market recovers, all that can be gleaned is that a shock occurred at some point during that year.

**Figure 11**




The rolling variance for boxed beef is very similar to the calculated variance, as seen in the other markets between 2014 and 2017 there were times when the market had enough transactions. Figure 12 does show how the beef cutout has been losing transactions steadily over the past 15 years. Unless there is a significant change in market reporting regulations, it is unlikely that any of these markets will increase their cash negotiations.

**Figure 12**




## 4.2 Measurement of Accuracy Range

The second manipulation of Chebyshev's inequality takes the transactions that have occurred in the market and provides a calculated accuracy level instead of an arbitrary number. Table 18 includes the average yearly price, the calculated[9] *c* and the prices plus or minus *c*. For the 5-Area live market, the values for *c* used in the previous section are representative of what the calculated values are. As the calculated σ increases the pricing accuracy range increases. It is important to note that as accuracy increases the range decreases and as accuracy decreases the range increases. As can expected the range widens most between 2014 and 2017 during a time of extreme volatility in the market.

[9] All calculations use a 90% probability

**Table 18** 5-Area Live Calculated Pricing Accuracy

| Year | Price | Calculated *c* (±) | Price c+ | Price c- |
|---|---|---|---|---|
| 2002 | 67.30 | 0.24 | 67.54 | 67.06 |
| 2003 | 83.84 | 0.56 | 84.40 | 83.29 |
| 2004 | 84.37 | 0.22 | 84.60 | 84.15 |
| 2005 | 87.55 | 0.26 | 87.82 | 87.29 |
| 2006 | 86.13 | 0.28 | 86.41 | 85.85 |
| 2007 | 92.62 | 0.22 | 92.83 | 92.40 |
| 2008 | 92.81 | 0.32 | 93.12 | 92.49 |
| 2009 | 83.18 | 0.14 | 83.32 | 83.04 |
| 2010 | 94.92 | 0.36 | 95.28 | 94.57 |
| 2011 | 114.50 | 0.47 | 114.97 | 114.03 |
| 2012 | 122.80 | 0.33 | 123.13 | 122.46 |
| 2013 | 125.92 | 0.40 | 126.31 | 125.52 |
| 2014 | 154.36 | 0.91 | 155.26 | 153.45 |
| 2015 | 147.98 | 1.81 | 149.80 | 146.17 |
| 2016 | 120.92 | 1.13 | 122.05 | 119.78 |
| 2017 | 121.04 | 0.77 | 121.81 | 120.27 |
| 2018 | 116.69 | 0.56 | 117.25 | 116.13 |
| 2019 | 116.79 | 0.80 | 117.59 | 115.99 |

**Figure 13**


In Figure 13, the pricing accuracy ranges are barely distinguishable when they are close to $0.25 however, in 2015 the range is clearer. In a more efficient market, the error bars would

be almost 0. For Nebraska, outside of 2015 and 2016, the pricing range seems to land around $0.50, $1.00, and $1.50. These calculations better inform what levels of accuracy are appropriate for each market. It has been discussed that some market participants are willing to give up some pricing accuracy and these tables show how much market participants could give up, given prices and actual transactions. Although these measures provide a range of prices, it is understood that there are several prices that will fall above and beneath these levels.

**Table 19** Nebraska Live Calculated Pricing Accuracy

| Year | Price | Calculated *c* (±) | Price c+ | Price c- |
|---|---|---|---|---|
| 2002 | 67.13 | 0.62 | 67.76 | 66.51 |
| 2003 | 84.47 | 1.44 | 85.91 | 83.02 |
| 2004 | 84.45 | 0.52 | 84.97 | 83.92 |
| 2005 | 87.31 | 0.68 | 87.99 | 86.63 |
| 2006 | 85.77 | 0.65 | 86.42 | 85.13 |
| 2007 | 92.17 | 0.57 | 92.75 | 91.60 |
| 2008 | 92.38 | 0.83 | 93.22 | 91.55 |
| 2009 | 82.78 | 0.39 | 83.17 | 82.39 |
| 2010 | 94.71 | 0.88 | 95.59 | 93.83 |
| 2011 | 115.02 | 1.09 | 116.11 | 113.93 |
| 2012 | 123.05 | 0.66 | 123.71 | 122.39 |
| 2013 | 126.25 | 0.72 | 126.98 | 125.53 |
| 2014 | 154.91 | 1.39 | 156.30 | 153.53 |
| 2015 | 148.20 | 3.02 | 151.22 | 145.18 |
| 2016 | 120.91 | 1.92 | 122.83 | 118.99 |
| 2017 | 121.17 | 1.29 | 122.47 | 119.88 |
| 2018 | 116.77 | 0.88 | 117.66 | 115.89 |
| 2019 | 117.10 | 1.39 | 118.50 | 115.71 |

Due to the smaller number of transactions in the Iowa-Minnesota market, the pricing accuracy range increases to compensate. In Figure 14, each error bar is the pricing range at each price. An understanding of this calculation could help producers keep better track of how their prices compare to the market.

**Table 20** Iowa-Minnesota Live Calculated Pricing Accuracy

| Year | Price | Calculated *c* (±) | Price c+ | Price c- |
|---|---|---|---|---|
| 2002 | 66.97 | 1.12 | 68.10 | 65.85 |
| 2003 | 83.85 | 2.58 | 86.43 | 81.27 |
| 2004 | 83.91 | 0.82 | 84.74 | 83.09 |
| 2005 | 86.80 | 1.16 | 87.96 | 85.65 |
| 2006 | 85.41 | 0.96 | 86.37 | 84.44 |
| 2007 | 91.89 | 0.78 | 92.67 | 91.11 |
| 2008 | 91.46 | 1.13 | 92.59 | 90.33 |
| 2009 | 82.43 | 0.56 | 82.99 | 81.87 |
| 2010 | 94.25 | 1.11 | 95.36 | 93.14 |
| 2011 | 114.93 | 1.35 | 116.28 | 113.58 |
| 2012 | 122.65 | 0.76 | 123.41 | 121.89 |
| 2013 | 125.89 | 0.84 | 126.73 | 125.05 |
| 2014 | 153.83 | 1.74 | 155.57 | 152.09 |
| 2015 | 147.15 | 3.50 | 150.65 | 143.65 |
| 2016 | 119.44 | 3.17 | 122.61 | 116.27 |
| 2017 | 120.66 | 2.05 | 122.71 | 118.60 |
| 2018 | 116.41 | 1.30 | 117.71 | 115.11 |
| 2019 | 117.70 | 1.57 | 119.26 | 116.13 |

**Figure 14**

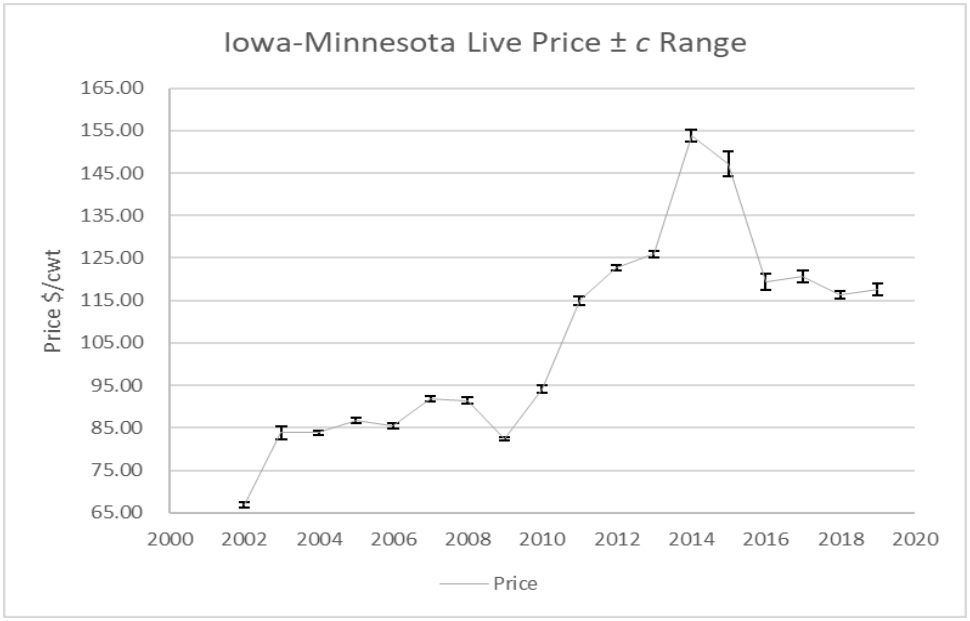


**Table 21** 5-Area Dressed Calculated Pricing Accuracy

| Year | Price | Calculated *c* (±) | Price c+ | Price c- |
|---|---|---|---|---|
| 2002 | 106.41 | 0.40 | 106.82 | 106.01 |
| 2003 | 133.95 | 1.14 | 135.09 | 132.81 |
| 2004 | 133.92 | 0.41 | 134.33 | 133.51 |
| 2005 | 138.72 | 0.51 | 139.23 | 138.21 |
| 2006 | 135.86 | 0.45 | 136.31 | 135.41 |
| 2007 | 146.43 | 0.41 | 146.83 | 146.02 |
| 2008 | 146.69 | 0.44 | 147.13 | 146.26 |
| 2009 | 131.79 | 0.24 | 132.03 | 131.56 |
| 2010 | 151.31 | 0.58 | 151.88 | 150.73 |
| 2011 | 183.52 | 0.81 | 184.33 | 182.71 |
| 2012 | 194.77 | 0.58 | 195.35 | 194.19 |
| 2013 | 200.35 | 0.54 | 200.89 | 199.80 |
| 2014 | 244.21 | 1.42 | 245.63 | 242.79 |
| 2015 | 234.16 | 2.75 | 236.91 | 231.41 |
| 2016 | 190.93 | 1.98 | 192.91 | 188.95 |
| 2017 | 192.45 | 1.63 | 194.09 | 190.82 |
| 2018 | 185.09 | 1.19 | 186.28 | 183.90 |
| 2019 | 187.40 | 1.46 | 188.86 | 185.93 |

Table 21, shows that the pricing accuracy range increases for the dressed market to roughly $0.50, $1.50, and $2.00. For this measurement, prices are left in terms of dressed instead of being converted to live prices. The dressed market sustains wider pricing ranges after the market shock unlike the live market that returns to a narrower price range. The boxed beef cutout has a similar pricing accuracy range to the dressed market. Prices for dressed cattle and the beef cutout are much more similar to each other than they are to the live prices due mainly to the fact that they are sold at carcass weights[10].

[10] Since the cutout value is made up of the primal cuts it is most comparable to carcass weight as whole.

**Table 22** Boxed Beef Cutout Calculated Pricing Accuracy

| Year | Price | Calculated *c* (±) | Price c+ | Price c- |
|---|---|---|---|---|
| 2004 | 136.87 | 0.64 | 137.51 | 136.24 |
| 2005 | 141.09 | 0.74 | 141.83 | 140.36 |
| 2006 | 139.86 | 0.40 | 140.26 | 139.46 |
| 2007 | 145.27 | 0.66 | 145.93 | 144.60 |
| 2008 | 150.42 | 0.81 | 151.23 | 149.62 |
| 2009 | 138.64 | 0.45 | 139.10 | 138.19 |
| 2010 | 154.19 | 0.90 | 155.09 | 153.28 |
| 2011 | 178.09 | 0.70 | 178.79 | 177.39 |
| 2012 | 186.35 | 0.56 | 186.90 | 185.79 |
| 2013 | 191.34 | 0.67 | 192.01 | 190.67 |
| 2014 | 235.74 | 1.81 | 237.55 | 233.94 |
| 2015 | 235.01 | 2.76 | 237.77 | 232.26 |
| 2016 | 203.26 | 2.31 | 205.57 | 200.95 |
| 2017 | 206.22 | 2.23 | 208.44 | 203.99 |
| 2018 | 210.32 | 1.00 | 211.31 | 209.32 |
| 2019 | 209.43 | 1.90 | 211.34 | 207.53 |

As mentioned before, *c* is calculated using all 3 measures of the variance. For the 1st difference estimation of the variance, prices and transactions remain the same for each regional market. The interpretation for c changes with this method and the range is now the difference between one market and another. Nebraska estimated has slightly wider pricing ranges between 2003 and 2008 than the calculated. However, in 2015 the estimated range is about half of what it is for the calculated range.

**Table 23** Nebraska Live 1st Difference Pricing Accuracy

| Year | Price | Estimated *c* (±) | Price c+ | Price c- |
|---|---|---|---|---|
| 2002 | 67.13 | 0.54 | 67.67 | 66.60 |
| 2003 | 84.47 | 1.59 | 86.06 | 82.88 |
| 2004 | 84.45 | 1.24 | 85.69 | 83.21 |
| 2005 | 87.31 | 0.80 | 88.11 | 86.50 |
| 2006 | 85.77 | 0.89 | 86.66 | 84.88 |
| 2007 | 92.17 | 0.74 | 92.92 | 91.43 |
| 2008 | 92.38 | 0.87 | 93.26 | 91.51 |
| 2009 | 82.78 | 0.66 | 83.44 | 82.12 |
| 2010 | 94.71 | 0.79 | 95.50 | 93.93 |
| 2011 | 115.02 | 1.19 | 116.21 | 113.84 |
| 2012 | 123.05 | 0.74 | 123.79 | 122.31 |
| 2013 | 126.25 | 0.80 | 127.05 | 125.45 |
| 2014 | 154.91 | 1.34 | 156.26 | 153.57 |
| 2015 | 148.20 | 1.48 | 149.68 | 146.72 |
| 2016 | 120.91 | 1.43 | 122.34 | 119.48 |
| 2017 | 121.17 | 1.15 | 122.32 | 120.03 |
| 2018 | 116.77 | 1.07 | 117.84 | 115.71 |
| 2019 | 117.10 | 1.21 | 118.32 | 115.89 |

**Table 24** Iowa-Minnesota Live 1st Difference Pricing Accuracy

| Year | Price | Estimated *c* (±) | Price c+ | Price c- |
|---|---|---|---|---|
| 2002 | 66.97 | 0.94 | 67.91 | 66.04 |
| 2003 | 83.85 | 1.42 | 85.27 | 82.43 |
| 2004 | 83.91 | 1.24 | 85.16 | 82.67 |
| 2005 | 86.80 | 1.18 | 87.98 | 85.63 |
| 2006 | 85.41 | 1.30 | 86.70 | 84.11 |
| 2007 | 91.89 | 1.16 | 93.05 | 90.73 |
| 2008 | 91.46 | 1.39 | 92.86 | 90.07 |
| 2009 | 82.43 | 1.23 | 83.66 | 81.20 |
| 2010 | 94.25 | 0.88 | 95.13 | 93.37 |
| 2011 | 114.93 | 1.31 | 116.24 | 113.62 |
| 2012 | 122.65 | 1.36 | 124.01 | 121.29 |
| 2013 | 125.89 | 1.57 | 127.46 | 124.32 |
| 2014 | 153.83 | 1.39 | 155.22 | 152.44 |
| 2015 | 147.15 | 1.37 | 148.52 | 145.79 |
| 2016 | 119.44 | 2.16 | 121.60 | 117.28 |
| 2017 | 120.66 | 1.96 | 122.61 | 118.70 |
| 2018 | 116.41 | 1.55 | 117.95 | 114.86 |
| 2019 | 117.70 | 1.37 | 119.07 | 116.32 |

As in the calculated price range, the estimated range is larger than the other regional market due to the number of transactions. Like the comparison between accuracy measures for Nebraska, Iowa also sees wider ranges between 2003 and 2008. During the market shock however, the estimated and calculated ranges do not deviate from each other as much which is consistent with the transaction measures. The rolling variance or in this case standard deviation measure for *c* is shown in Figure 18 in the appendix, these graphs show the accuracy ranges and how they move over time. The 5-Area live market only touches the $1.00 level once whereas for dressed cattle it crosses the $1.00 level several times. The live Nebraska market crosses the $1.50 level but follows the 5-Area market very closely. The boxed beef range shows significant volatility between 2014 and 2017, this creates a challenge when trying to define an accurate price. When comparing the dressed market and the cutout, there are similar spikes however, the dressed market does not contract and retract and extremely as the cutout does during this time period. Overall, all 3 of these accuracy measures can help inform how market conditions can affect pricing accuracy on a yearly and weekly basis.

# Chapter 5 - Conclusions

This thesis was written with the goal of shedding light on the current situation of market thinness. Several studies have addressed this topic and have offered different models and perspective of this issue. Chebyshev's inequality, though simple in its design and application, offers an empirical way to look market thinness. For the live cattle market there are sufficient transactions in most weeks (outside of the market crash) at the $0.50 level of accuracy and there are more than sufficient transactions at the $1.00 level. Currently Nebraska has the most cattle being traded via cash negotiations both in the live and dressed markets. Iowa-Minnesota though a smaller market, has increased their negotiated transactions rather than decreasing. Kansas still has some price discovery occurring however, they are trending down looking forward. Texas-Oklahoma-New Mexico and Colorado continue to have insufficient transactions and price discovery in these regions is questionable.

The three measurements of the variance add to previous literature in their comparison and the ability to isolate the weeks where there are not enough transactions for accurate price discovery. The first measurement highlights shocks to the market that cause disruptions in price discovery. The use of the 1$^{st}$ differences estimation allows us to see how the regional markets interact with each other and when prices in the individual markets converge or diverge from each other. The third measurement uses a rolling variance to track changes in the market on a weekly basis. This third measure is the most important addition to the literature since it shows clearly which time periods actual transactions are equal to or greater than transactions needed at a given probability and accuracy level.

For the accuracy measurements, the same methods used to calculate the variance were applied to the SD. During "normal" market conditions, it seems that $0.50, $1.00, and $1.50 are

the ranges that fit all markets evaluated best. With this knowledge it helps confirm the accuracy levels chosen for the transaction measurements. In a market with perfect price transmission pricing accuracy would not be as big of an issue but that is not the case so having an accurate gauge of how far prices can deviate from the true price can help producers and packers alike know where they stand as they look to market their cattle.

There are a couple of limitations to this study with the method and the data. In Chebyshev's inequality the equations can be manipulated in such a way that depending on the transaction size, probability, or accuracy level used, one could either say that there are not enough transactions occurring in the market or that there are plenty. It is important to take these measurements than with a grain of salt and only use them as an estimation and not as a definitive answer to the market thinness question. Since the USDA can only report head of cattle and not individual market transactions it is hard to say whether these measures are actually consistent with what is occurring in the market. The reports themselves are weighted averages of the prices, weights, and head of cattle so as the data is evaluated further, true market volatility and the true variance in prices are not accounted for. In Ajewole et al., 2016, they propose the use of median absolute deviation instead of a weighted average for the USDA report in order to better represent the information in these reports. Further work on this topic could include how the futures market interacts with the live, dressed, and boxed beef markets within the methods used. It would also be interesting to see how market thinness effect the feeder cattle market and where price discovery occurs. Bessler & Davis, 2004 and Stockton et al., 2010 determine which weight group and sex contributes most to price discovery in Texas and Nebraska respectively using similar methods. Another limitation of this research is that it assumes that all the cattle are homogeneous

and do not deviate in quality. If one were able to account for quality differences within this study, it could be more accurate in simulating actual market conditions.

This study is meant to be an objective measure of market thinness. There are many reasons why market participants have deviated from using the cash market. The efficiency of formula trading and other marketing arrangements often outweigh the benefits of having more trade in the cash markets. Regardless of the benefits of having a thicker cash market, the cost to producers and packers could be detrimental to the market as a whole. Some market participants and policy makers are concerned however, that the cash market is as a point that the benefits of alternative market arrangements could be outweighed by the cost of a thin cash market. Regardless of which side you stand on, markets will adjust and change either through the initiative of the participants or by necessity. It is in the interest of both market participants and policy makers to be actively pursuing a solution together rather than waiting until change inevitable comes.

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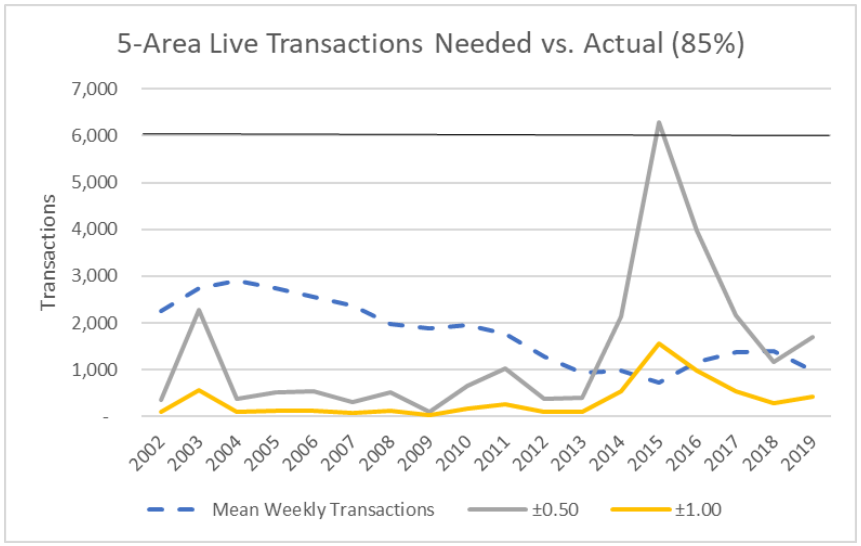
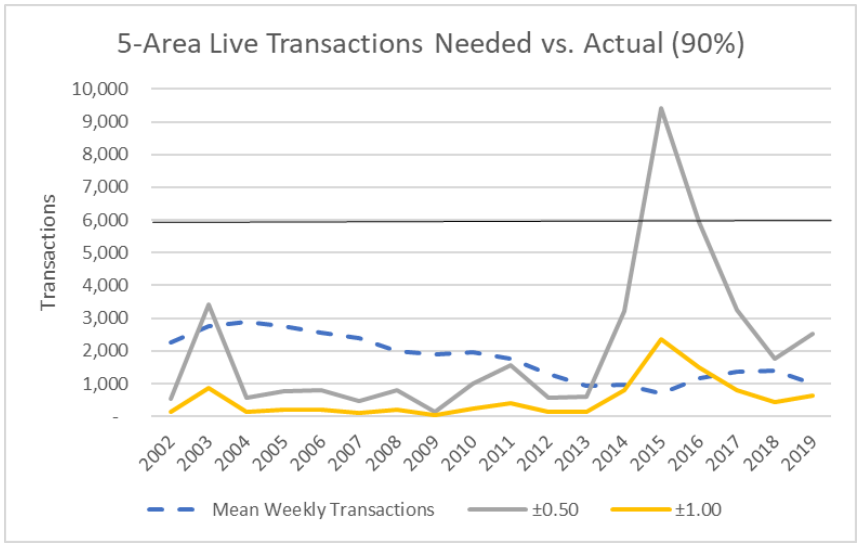
# Appendix

**Figure 15 Appendix**



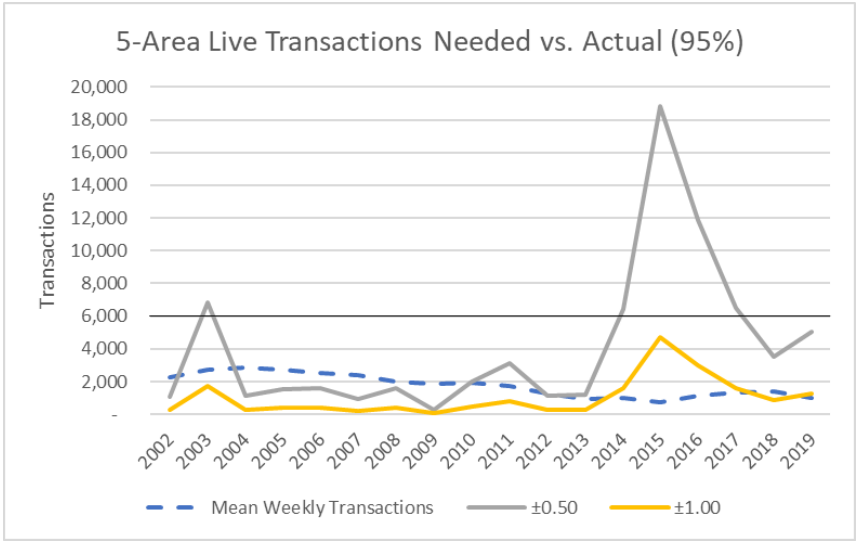
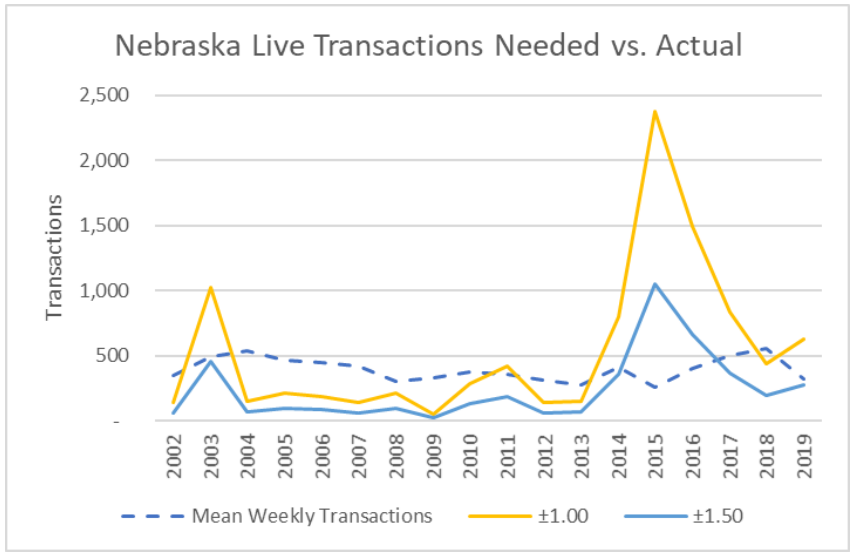
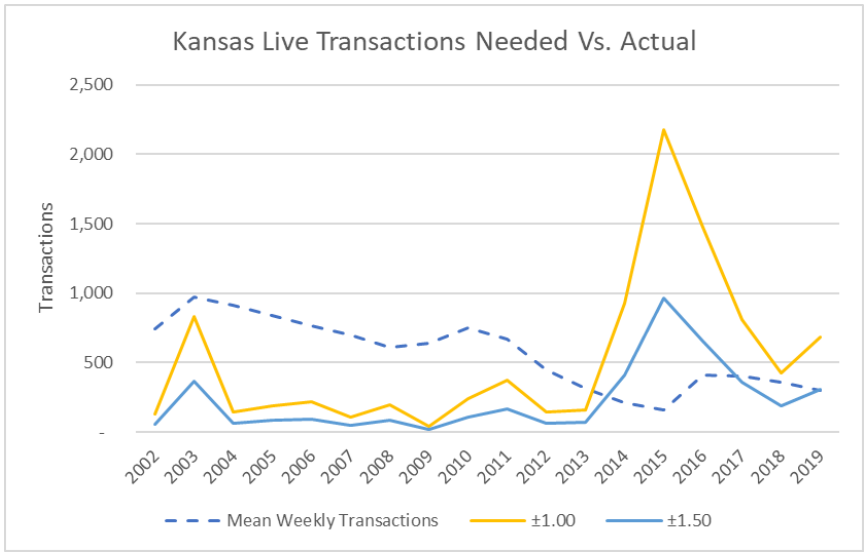
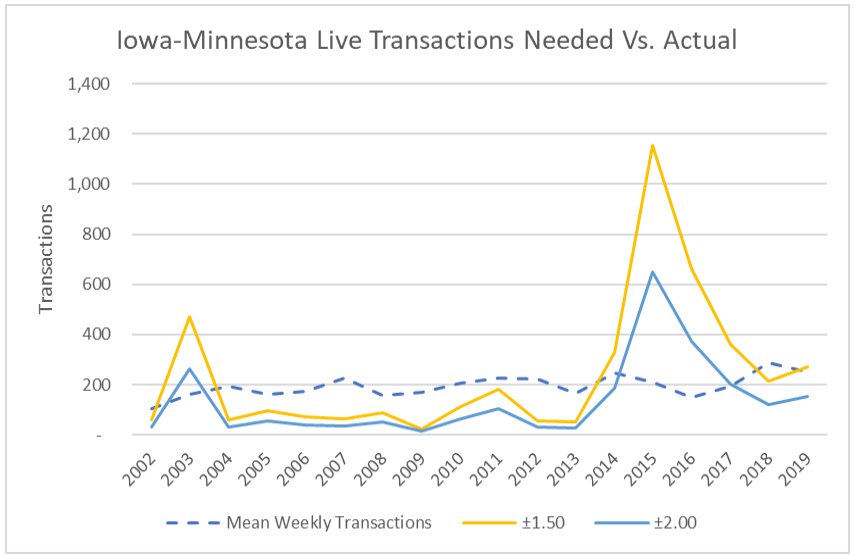



**Figure 16 Appendix**



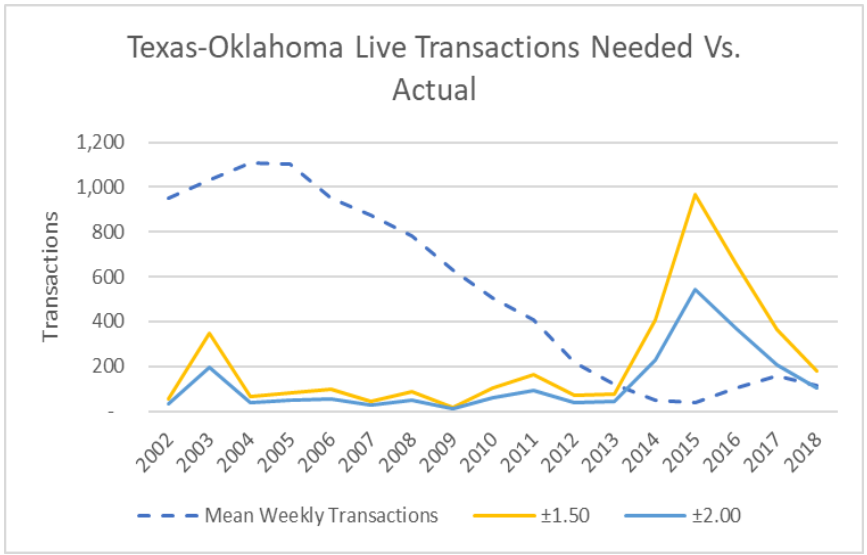
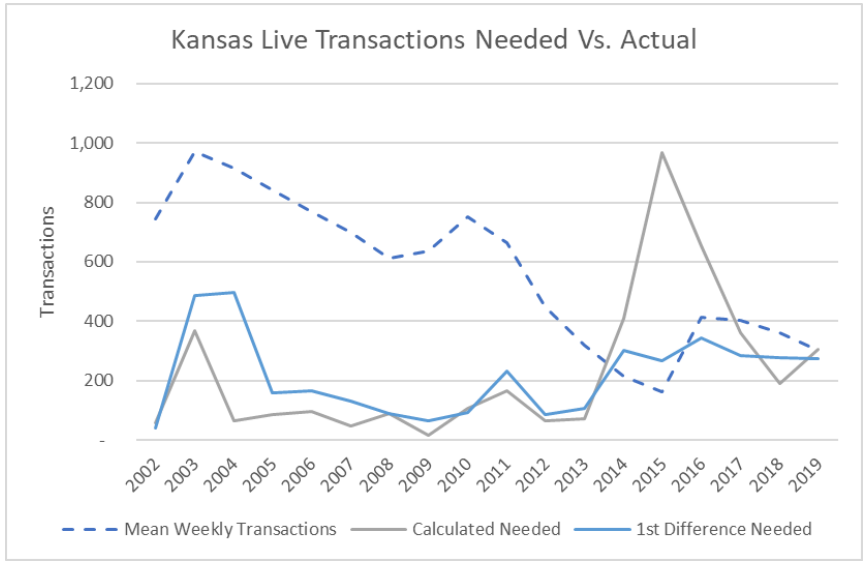
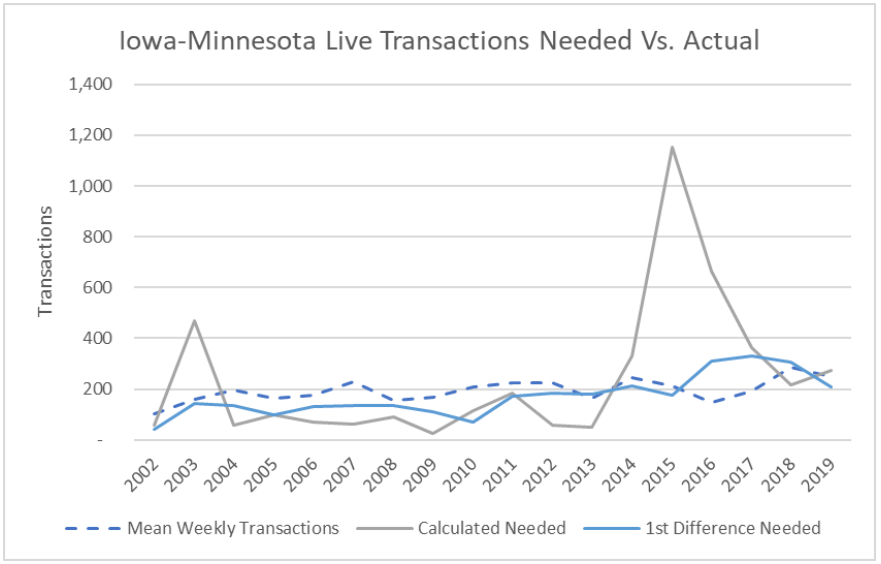
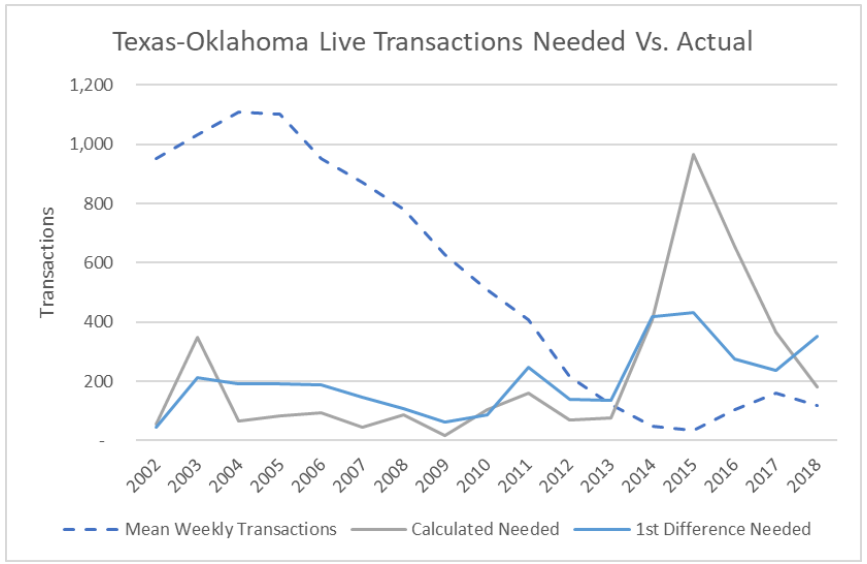



**Figure 17 Appendix**



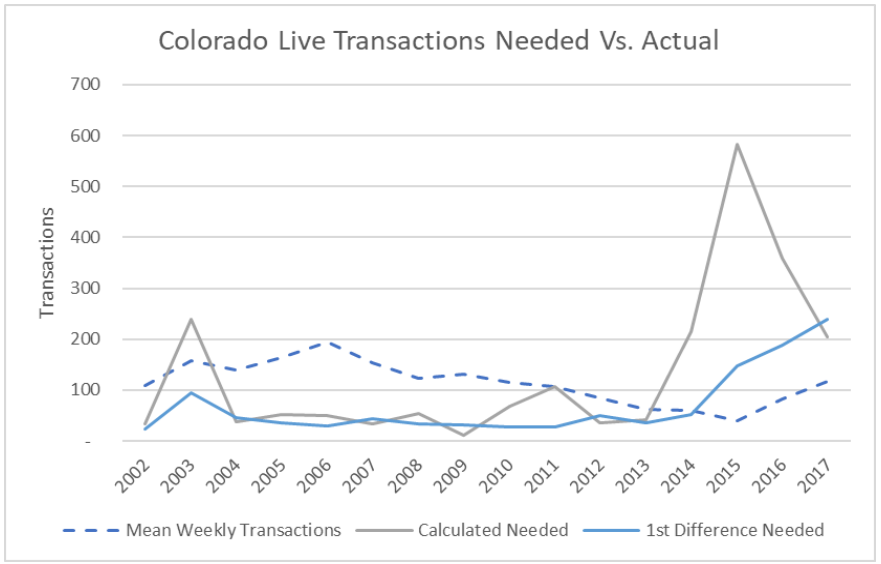



**Figure 18 Appendix**