Price Discovery Research Project – Objective Measures Findings Summary

Stephen R. Koontz – Stephen.Koontz@ColoState.Edu – 970/491-7032
Department of Agricultural and Resource Economics
Colorado State University

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This objective-measures findings summary – linking the thinning of cash fed cattle markets to the quality of price discovery – is a deliverable on the Price Discovery Research Project conducted for the National Cattlemen's Beef Association. A majority of fed cattle are marketed through alternatives to the cash market and the portion of cash marketings continue to shrink – or thin. The causes are numerous but all translate into bottom-line economics. A thinning cash market is the result of market participants not using the cash market and using of alternative marketing arrangements (AMAs). For the fed cattle industry AMAs are largely formula cattle and forward contracts.

The purpose of this summary is to discuss, "How thin is too thin?" Another report communicates the reasons for thinning cash markets – there are strong economic incentives for individual businesses to use alternatives to the cash market and it is always communicated by those businesses that they were acting on what is in their best interest. However, substantial AMA use may not the best for the overall market and its participants as a group. Therefore, another report communicates what to do about it. There it is discussed that the public good nature of price discovery, of functioning cash markets, and price reporting need to be recognized and addressed. This report focuses on communicating what levels of cash trade are needed in the various USDA AMS price reporting regions for price discovery to be significant and robust. The report does not rely on perceptions or rhetoric. The report constructs objective measures of the impact of the thinning cash market on the quality of price discovery in negotiated cash fed cattle markets.

So the cash market is shrinking for economic reasons and the research goal is to determine how small the residual cash market can get before there is a price discovery problem. Econometric results using historic data are presented, first, in the context of the classic framework. Second, new results are presented in a framework used commonly by agricultural economists to measure price discovery. Third, new results are presented in the framework used by financial market economists to measure price discovery in multiple markets. These three frameworks are discussed next. The data and samples used follow. And then results are presented.

Three Approaches

To measure price discovery, we first have to define what price discovery is. Price discovery is work performed by individuals attempting to buy and sell in a marketplace. Price discovery is the process of gathering information on current and expected future supply and demand, formulating bids and offers in negotiation, and incorporating new and changing economic information (Forker; Purcell; Tomek and

Robinson). Price discovery is work. It is the work of market participants in discovering how changing market conditions and anticipated market conditions impact price. Price discovery is revealed and measured by price changes. Different markets for fed cattle will first reveal changes in underlying market fundamentals and market psychology. The market that is first impacted will then lead changes in other market prices. Objective measures examine the timing and strength of this price change leadership and this is the agricultural economic research definition (see, e.g., Goodwin and Schroeder).

Financial markets research measures price discovery by examining how closely individual markets influence an underlying market common trend (see Hasbrouck; Gonzalo and Granger; Yan and Zivot). Whereas the agricultural economic research focuses on changing prices the financial market research focuses on adherence to an equilibrium condition. Financial markets tend to have less dynamic and more contemporaneous relationships. The topic of price discovery has become important in financial markets because the same financial asset is traded in multiple markets. Research is interested in determining relative market importance in the conduct of price discovery. Parameters from statistical models can be used to construct the common trend. The trend is comprised of weights associated with individual asset prices. The weights measure the contribution of individual assets to the common trend and thus measure the contribution of those assets to price discovery. Assets in the models here are cattle and beef prices.

The two approaches are complementary. Both are useful and unique. The agricultural economics approach examines dynamic temporal relationships between prices: Which markets lead and which markets follow in the price adjustment process? The finance approach is to recognize and measure an underlying equilibrium price for the asset. And then determine, what are the relative weights of the individual markets in contributing to the equilibrium price?

A system of econometric models are used to produce the standard tools for measuring price discovery. There are a variety of specifics within this modelling framework that provide information and different perspectives. Agricultural economics research relies on results from temporal information flow testing and measures of strength of this flow. Price changes reveal price discovery. The question is which markets change first and which markets then follow? For example, price discovery is historically strong in the Texas-Oklahoma-New Mexico region. Price changes in this market reveal changes in underlying market supply and demand fundamentals and changes in market psychology. Prices in other regions – Kansas, Colorado, Nebraska, and Iowa – then historically make similar changes. Likewise, change in live cattle futures prices and downstream values of beef can lead changes in fed cattle market prices.

Similarly, parameters within the econometric model can be used to construct the weights associated with and also construct an implied underlying common trend. Financial markets research assesses price discovery by measuring how closely individual markets contribute to the underlying market common trend. Parameters from the econometric model can be used to construct the variable that is the common trend underlying the fed cattle and beef market. The component prices are each weighted to construct the trend. The weights reveal the relative importance of each different market in price discovery. The weights can be examined themselves and the correlation between the individual market prices and the common trend can be examined to assess price discovery.

So an econometric system of models is used that measures the timing and strength of price changes and the degree with which individual markets follow the common trend. Measuring price discovery is one thing and linking these measures to thin markets is the next step. These price discovery measures over time need to be compared to the underlying cash market volumes over time.

Tomek is the classic work on thin markets. There are other classic publications that address the issue of thinning markets from an institutional perspective (E.g., Hayenga and Hayenga et al.). But Tomek's approach was empirical and almost all subsequent research on thinning cash markets apply the concepts he developed (See, e.g., Franken and Parcell, and Ward and Choi).[1]

This approach starts with Chebyshev's inequality

$$\Pr(|\overline{X} - \mu|) \le \mathrm{k}) \ge \frac{1}{(\sigma^2 / Nk^2)}$$

where $\overline{X}$ is the sample statistic of interest and a random variable, μ is the unknown population parameter measured by the sample statistic, k is the error due to sampling, σ^2 is the variance of the underlying random variable, and N is the sample size. Tomek's work was innovative in that he linked this inequality to the thin markets question. The sample statistic is the observed market price, the population parameter is the underlying equilibrium price, and the variance is associated with the random variable. The summary statistic for and variance of market price are estimated from data. Applied research then assumes a pricing error (k) and a persistence of the pricing error (Pr). With these four measures a sample size (N) can be solved for. This sample size is the number of transactions needed for the observed market price – or its summary statistic – with the measured variance to be within the pricing error for a given probability

$$N = \sigma^2 / (1 - \Pr)k^2$$

This is one approach to answering the how thin is too thin question and the implied number can be compared to the actual number of transactions. As an example, suppose σ = $2.00/cwt, Pr = 95%, and k = $1.00/cwt then N = $(2^2)/((1 - 0.95)\times 1^2) = 80$ transactions. Similarly, the pricing error (k) can be solved for

$$k = \sqrt{\sigma^2 / ((1 - \Pr)N)}\ .$$

Given the estimated and assumed parameters, and the actual number of transactions, the pricing error communicates how closely the market price will measure the underlying equilibrium price. As an example, suppose σ = $2.00/cwt, Pr = 95%, and N = 20 transactions then the pricing error is k = $\sqrt{(2^2/((1 - 0.95)\times 20))} = $2.00/cwt. Both of these results will be presented.

Empirical work has used a variety of measures of the price mean and variance. Original work used means and variances of the price series. Subsequent work has used conditional means – econometric model predictions and the error variances associated with those models. All work following Tomek's approach though continues to need the researcher to make assumptions about the magnitude of the

[1] Alternative approaches specifically have the benefit of transactions data (see, for example, Rhodus, Baldwin and Henderson, and Peterson) or data from experiments (see Nelson and Turner, and Anderson et al.)

pricing error (k) and the persistence (Pr). This work will do that well and the discussion will be modified in the context of information gathered from interviews.

Conditional means and error variances are used from an error-correction vector autoregression (ECVAR) model of cattle and beef prices. The standard ECVAR is

$$\Delta Y_t = (\alpha\beta')Y_{t-1} + \sum_{i=1}^{p} \Gamma_i \Delta Y_{t-i} + \Phi_t + \varepsilon_t$$

where Y is the vector of prices, Δ indicates first differences or the change in price between t and t-1 time periods, Γ_i are matrices of autoregressive parameters at lag i, p is the lag length, α and β are the cointegration parameters, Φ is a catch-all for other terms like trends or intercept coefficients, and ε the vector of errors. There are seven prices in the system: five fed cattle cash market prices from the USDA AMS reporting regions, the nearby live cattle futures contract price, and a downstream beef value. Weekly prices are used from January 2002 through December 2015. This is the time period when livestock mandatory price reporting was instituted and after the initial problems. The quality grade weighted boxed beef composite value has added to it the weekly beef byproduct value. Thus, the downstream beef value is a boxed beef and byproduct value. This modeling framework is the industry standard (see, e.g., Lee, Ward, and Brorsen).

Thus, the price data are used within the econometric systems of equations to estimate the parameters that describe the temporal dynamics and the equilibrium relationships. The models can be used to produce predicted values or in other words what the models say the prices should be. These can be compared to the actual prices to calculate the price errors. The price errors are used to calculate the variance term (σ^2) in Tomek's approach. The more that individual market prices follow historical dynamics and do not depart from historical equilibrium relationships then the fewer the transactions that are needed to discovery price. The more volatility and variability in market prices then the more transactions that will be needed. This is a statistical sampling argument based on the Chebyshev inequality. The more predictable that underlying relationships are the fewer N that are needed. And the more unpredictable things are the more N that are needed.

It is useful to present a little more detail from the ECVAR. These details can be burdensome but they communicate the objectively of the price discovery measures. This discussion takes us from the Tomek approach to the second and third approach – those used by agricultural economists and financial market economists. The vector Y_t are all of the prices at week t.

$$Y_t = \begin{bmatrix} Texas_t \\ Kansas_t \\ Colorado_t \\ Nebraska_t \\ Iowa_t \\ LiveCattleFutures_t \\ BeefValue_t \end{bmatrix}$$

So in the econometric modelling, prices changes in all of the markets in week t are explained by prior price changes and an equilibrium relationship between the prices. The modelling framework includes seven separate models. The matrix Γ_1 appears as follows

$$\Gamma_1 = \begin{bmatrix} \gamma_{11}^1 & \gamma_{12}^1 & \gamma_{13}^1 & \cdots & \gamma_{17}^1 \\ \gamma_{21}^1 & \gamma_{22}^1 & \gamma_{23}^1 & \cdots & \gamma_{27}^1 \\ \gamma_{31}^1 & \gamma_{32}^1 & \gamma_{33}^1 & \cdots & \gamma_{37}^1 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \gamma_{71}^1 & \gamma_{72}^1 & \gamma_{73}^1 & \cdots & \gamma_{77}^1 \end{bmatrix}$$

and γ_{11}^1 measures the impact of the prior week's change in the Texas price on the current Texas price change and γ_{17}^1 measures the prior week's change in the downstream beef value on the current Texas price change. Other parameters in the row measure the impact of other market prices. Thus, the Γ's measure how current price changes are associated with past price changes. The agricultural economics approach focusses on the use of these past price dynamics: which prices lead other prices and which prices follow? For example, we can examine if changes in the Texas-OK-NM price leads price changes in Kansas, Colorado, Nebraska and Iowa. Likewise, we can examine if price changes in Kansas, Colorado, Nebraska, and Iowa each lead price changes in Texas-OK-NM. Further, these tools will measure the strength of the dynamic relationships. The Γ's objectively measure this. We can think of these relationships as information flows. New information changes individual prices, participants in other markets can observe these new prices, and then the other market prices change. The information flows across markets.

The term (αβ′) that is the combination of two matrices, β that set up the equilibrium relationship among the prices and α that measures the reaction of each price to departures from these equilibrium relationships. For example, β is assumed to be

$$\beta' = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & 1 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 1 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 1 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$

and this implies simply that all the cash prices and futures price are tied to the downstream beef value. When multiplied by the price vector, the first row $z_{1t} = P_{1t} - P_{7t} - \mu_1$ is the difference between the Texas-OK-NM fed cattle price and the downstream beef value – also adjusted for the mean difference (μ). The second row measures Kansas relative to the boxed beef value and the last row measure live cattle futures relative to the beef value. Thus, $\beta' Y_{t-1}$ in the ECVAR is the difference between all the fed cattle prices and the boxed beef downstream value. Note that since each regional fed cattle market is measured relative to the downstream beef value then there are also equilibrium relationships between all the regional fed cattle prices. Seven prices and six equilibrium relationships imply that all prices are related and tied together.

The matrix α

$$\alpha = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} & \alpha_{14} & \alpha_{15} & \alpha_{16} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} & \alpha_{24} & \alpha_{25} & \alpha_{26} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} & \alpha_{34} & \alpha_{35} & \alpha_{36} \\ \alpha_{41} & \alpha_{42} & \alpha_{43} & \alpha_{44} & \alpha_{45} & \alpha_{46} \\ \alpha_{51} & \alpha_{52} & \alpha_{53} & \alpha_{54} & \alpha_{55} & \alpha_{56} \\ \alpha_{61} & \alpha_{62} & \alpha_{63} & \alpha_{64} & \alpha_{65} & \alpha_{66} \\ \alpha_{71} & \alpha_{72} & \alpha_{73} & \alpha_{74} & \alpha_{75} & \alpha_{76} \end{bmatrix}$$

then measures the reaction of the price changes in the different markets to these differences. So if the Texas-OK-NM price gets too far from the beef value then the Texas-OK-NM market may correct and α_{11} measures this. Likewise, if the Kansas (α_{12}) or Nebraska (α_{14}) or any other prices (α_{1i}) become far from the beef value then the Texas-OK-NM price may correct and the adjustments will be measured by the coefficients in the first row of α.

The financial economics approach makes detailed use of the α matrix. The orthogonal complement, $\alpha_{\perp}$, of α is calculated. The value of each of these elements is in part the contribution of the respective prices to the underlying equilibrium price or common market trend. For example,

$$\alpha_{\perp} = \begin{bmatrix} \alpha_{\perp 1} \\ \alpha_{\perp 2} \\ \alpha_{\perp 3} \\ \alpha_{\perp 4} \\ \alpha_{\perp 5} \\ \alpha_{\perp 6} \\ \alpha_{\perp 7} \end{bmatrix}$$

and if $\alpha_{\perp 1}$ is twice as large are $\alpha_{\perp 2}$ the Texas-OK-NM is twice as important as Kansas by this measure of price discovery. The elements in the orthogonal competent are multiplied by a matrix which is a combination of the Γ matrices and the vector of seven prices to construct an underlying fed cattle and beef market equilibrium price. This price or common trend will be presented and examined.

Finally, because each market price might adjust – or correct – based on difference between other regional markets and the boxed beef value then the α matrix needs to be used with the Γ's in measuring market price dynamics. This is recognized and done.

Data and Samples

Fed cattle prices were examined since the institution of mandatory price reporting: 2002-2015. The fed cattle market is essentially a weekly market. Bid and ask take place through the days of the week and a majority of the cash trade usually occurs on a single day. It is fairly common that daily cash prices are based on minimal volume for three to four days per week. The five USDA AMS weekly volume weighted average regional prices were examined: Texas-Oklahoma-New Mexico, Kansas, Colorado, Nebraska, and Iowa. Live weight and carcass weight prices are combined and carcass prices are converted to live

weight based on dressing percentages. (The 5-market weighted average was also used separately.) Price discovery in fed cattle markets is influenced by the live cattle futures market and the value of beef cuts. These two series are included. The futures series is a rolling nearby contract price. The series rolls to the next-to-nearby contract when nearby contract enters the delivery period. Thus, the futures series is an anticipated-price one-to-two months into the future. (Price changes are used in the models and price change are not calculated across the contract roll. Price changes for the same contract are calculated and then the rolling series is constructed.) The boxed beef composite value is a volume-weighted combination of USDA Choice and Select values. The composite value is converted to live animal weight using dressing percentages in the slaughter mix. Byproduct value is added to the boxed beef composite, in common units. The resulting downstream beef value reflects weighted valuations of Choice and Select beef cuts and aggregate byproduct value. The econometric modeling includes the 7 series – the 5 separate USDA AMS regional fed cattle prices along with the futures and beef prices – or a 3 series – the 5-market average with the futures and composite beef values.

The complete sample system of equations will be presented in summary and is used in the Tomek approach. To examine the changing price discovery process then subsamples of the entire sample period were estimated. Two year rolling subsamples were used: 2002-03, 2003-04, 2004-05, through 20014-15. Complete sample results will be presented partly in the tables and the rolling subsample results will be discussed in the context of changes over time as related to reductions in the volume of cash trade. Results for the rolling subsamples will be used to examine how price discovery changes over time and present the results of the second and third approaches.

Cash market volumes are reported through MPR. Weekly cash market volumes were collected for each regional market. The rolling sample process results in 13 models for each of the five markets. Thus, there are at least 65 (= 13×5) separate price discovery measurements for each tool. Some tools provide a separate measurement across the four other markets thus there are 260 (= 13×5×4) observations. We examine if the price discovery measures change across time and with the changing cash market volume using these observations. The rolling subsample model results are too numerous to report. Summaries of these results with changing cash market volumes will be discussed.

The weekly negotiated cash prices and volumes for the five regional markets are presented in Figures 1-5. The 5-market weighted average price and volume is presented in Figure 6. The figures are of the complete sample. (Live cattle futures and the downstream beef value are shown with the five regional prices in Figure 19.) The rolling subsample involves doing a complete analysis two-year blocks of the complete sample. The temporal price dynamic measures over time can be compared to the underlying cash market volumes over time so see if there is a link between cash market volume and the strength of price discovery. Are markets with reduced cash trade less important in the price discovery process?

Results from the Three Approaches

All of the seven prices series are nonstationary (see Table 1). Nonstationarity implies that the best guess for next week's price is this week's price and not the mean price. This is very reasonable as fed cattle prices drift up over the sample and then drift down in the last year. (Rolling a pair of dice is stationary: the best guess of the face value of a pair of fair dice is seven and not the value of the last roll.) Nonstationarity implies that the econometric model needs to use price changes and not price levels.

Finally, nonstationarity opens the possibility of a cointegrated system. (The cointegration terms are $(\alpha\beta')Y_{t-1}$ in the ECVAR. These terms are not needed if the data are not cointegrated.) Johansen tests for the order of cointegration are also conclusive (see Table 2). There are six cointegrating vectors and this implies that this is one common trend underlying all seven of the price series. The number of cointegrating vectors result is intuitive in that it implies there are pair-wise equilibrium relationships between all of the prices. For example, there is an equilibrium relationship between Texas and Kansas and an equilibrium relationship between Kansas and Colorado. These two pairwise relationships imply that there is also an equilibrium relationship between Texas and Colorado. Thus, all of the price series move together – regional fed cattle markets, live cattle futures, and the downstream beef value all follow an equilibrium relationship and any departure will not persist. Knowing any one price provides strong information about magnitude of all of the other prices. The common trend result is also intuitive in that there is one underlying market phenomena that is driving all seven of the price series. The model laid out in the prior section is exactly what the data suggests.

The α matrix measures the speed of adjustment back to equilibrium. These estimates are presented in Table 3. Negative elements of α are balancing or stabilizing effects. For example, a large difference between the Texas cash price and the beef value implies the Texas cash price is too high or too low relative to the beef value then the negative parameter estimate implies one or both prices are pushed back into balance. The Texas-beef value difference is balancing for all markets but Kansas and Nebraska – and the Nebraska parameter is a very small magnitude. The Colorado-beef value difference is also largely balancing. Nebraska and Iowa have some balancing effects. Positive elements in α imply destabilizing influences. We see that there are many positive estimates of α associated with the futures price. There are also destabilizing effects with Nebraska and Iowa and with Kansas. The difference between the futures price and the beef value does not pull the cash markets together – only the futures or beef markets.

First Approach: Tomek

The ECVAR for the complete sample is used here: weekly actual prices, predictions and residuals from the five cash market models were calculated and error variances were produced for each month in the sample. Each month has 4 or 5 observations. With an assumed pricing error (k) and probability, the number of transactions needed to establish a thick market can be calculated. These are the red lines presented in Figures 6 to 12 and are identified as the number of "needed" transactions. Mandatory price reporting provides the number of head marketed through negotiated cash. The number of transactions is not available and not obtainable by USDA AMS. Studies that examine fed cattle transactions data routinely find that 100 head is the average number in a transaction. Thus, the weekly volume marketed is aggregated by month divided by 100 to estimate the number of transactions per month. These are the black lines presented in Figures 6 to 12 and are identified as the estimated "actual" transactions. The 100 head per transaction assumption may be an issue with Iowa but the potential bias will be discussed with those results.

Using traditional pricing errors and probabilities, the Texas-Oklahoma-New Mexico regional market became too thin during 2014. The negotiated cash trade fell below 4% in early 2014 and has had weeks of zero cash trade. As important as the region is in cattle feeding, since 2014 it negotiates almost no

cash trade and likely performs little fed cattle price discovery. This event in the Texas-OK-NM region was fairly predictable. Cattle feeding in the southern plains are closely managed – feedlots are large, not diversified, and feeding costs tend to be higher except for winter months. Formula based marketing is common. In January 2013, Cargill Meat Solutions closed the Plainview, Texas cattle and beef processing plant after several years of poor margins and an outlook for continued negative margins. Plainview was a 4000 head per day plant and 16% of the packing capacity in the Texas Panhandle. Prior to its closure, packing capacity was much in excess of feeding capacity in that region. After its closure, those two capacities are much more in line.

This approach suggests that twenty thousand head per month are needed to have less than $1.00/cwt pricing error 95% of the time. This suggests 5,000 head per week are needed in Texas-OK-NM for the market not to be too thin. In late 2014 and periodically through 2015 there are spikes in the number of transactions needed. These spikes are smaller but similar to those seen in late 2003 and early 2004. The volatility in 2003-04 was caused by the uncertainty over the discovery of BSE in Canada and then eventual discovery in the US. The approach reveals that more transactions are needed when there is more market volatility. This happen in 2003-04 and happened in 2014-15. The market volatility in this later time period is uncharacteristic.

The recent change in the Texas-OK-NM region is similar to much of the history of Colorado. Colorado has had relatively little cash trade since 2008 and is too thin. Colorado drifted below a 5-7% cash trade in 2008. Kansas is similar but not as pronounced as the Texas-OK-NM region. The negotiated cash trade in Kansas became periodically too thin in mid-2014. There remains very small cash trade but, unlike Texas-OK-NM, there are cash trades in all weeks. The thickest market is reported is Nebraska. Cash trade in Nebraska varies between 15-35%. It is trending towards being too thin but the trend is not as pronounced as the Texas-OK-NM region and does not start with very low cash trade like Colorado. The cash trade in Nebraska through much of 2014 appears to be double or triple the volume that is needed for price discovery – within the parameters assumed. Finally, Iowa is similar to Nebraska. That region has the least persistent trend away from cash. However, the total volume in that market is small. It is also likely that there are more transactions than estimated due to smaller pen size transactions. But this issue may not play any role in qualifying the conclusions. All transactions may not need to be weighted equally. A few transactions of smaller pen sizes may be argued to be the same as one transaction with a large number of head. Regardless, it is Nebraska that is the thickest negotiated cash fed cattle market and likely does the majority of price discovery work in fed cattle markets.

How do the empirical results change when results for the interviews are considered? The industry communicated that it is willing to use information from considerably thinner markets. The acceptable pricing error was at least $1.00/cwt and the probabilities were all smaller than 95%. 80% was common. These parameters add little to the analysis though. Here almost any cash trade is useful, 1-2%, and the thinnest markets may not too thin. The “needed” line does not move down much as it is bounded by zero. The industry provided parameters communicate that 1-8 trades per week over a month are adequate. But this disagrees somewhat with how formulas are constructed – that there are head-minimums larger than this. Head minimums imply the need for 15-30 transactions per week. Formula transactions in Texas-OK-NM and Kansas are being valued using prices not from those USDA AMS reported regions because of the small cash trade.

So how thin is too thin? The approach recommends 20,000-25,000 head per month is needed. This is approximately 5,000-6,000 head per week. Regardless, 2014 was a watershed year for the southern plains and the reduction in price discovery. And it is likely that Kansas continues to follow the trend. Nebraska by contrast does not have the same problem. It has two to three times the needed negotiated cash transactions. Making a recommendation to the cattle industry is not a transparent exercise but based on these results less than 5% cash trade appears to be likely too thin. Establishing a cash trade greater than 5% would be needed. To be confident that cash trade contributes to robust price discovery then a cash trade greater than 10% is likely needed.

As an alternative to the number of transactions, Figures 13 to 17 present for the same regional markets the pricing errors for 95% and 80% probabilities. Specifically, in Figure 13, we see the pricing error spikes above $3.00/cwt for four of the last six months in 2014 in the Texas-OK-NM region when a 95% probability is used. The pricing error is $1.50/cwt when an 80% probability is used. (A smoothed same-color line is included to illustrate the pricing error without the variability.) The numbers of transactions in Kansas are higher during 2014 but we still observe an increase in the potential pricing error. The values are $1.00/cwt and $0.50/cwt for 95% and 80% probabilities. Finally, the pricing errors in the thickest market, Nebraska, are both below $0.50/cwt. This $0.50/cwt pricing error is small and suggests solid price discovery in Nebraska. But the $1.50-$3.00/cwt pricing errors for Texas-OK-NM are large. The $3.00/cwt is above most of the acceptable pricing errors discussed in the interviews.

In short, Nebraska is the thickest market and has adequate transactions such that there are little pricing errors with small persistence given the underlying variability market price. However, a similar statement cannot be made for the Texas-OK-NM region. In that region, the transactions are few enough to risk large pricing errors with persistent probability. And quality of price discovery in Kansas is in between that of Texas-OK-NM and Nebraska but with conditions much more close to Texas-OK-NM.

Second and Third Approaches: Agricultural and Financial Economics

Complete Sample Results

Tables 4 and 5 present the results of the information flow testing: what market price changes lead to price changes in other markets? Table 4 presents the significance associated with lagged other-market prices. For example, we reject the null hypothesis that past changes in Texas-OK-NM cash price does not cause current changes in Kansas prices at the 0.0285 level. Thus, past changes in Texas-OK-NM prices lead changes in Kansas prices. Likewise, we reject the null hypothesis that past changes in the Kansas cash price do not cause current changes in Texas-OK-NM prices at the 0.0002 level. Thus, past changes in Kansas prices lead changes in Texas-OK-NM prices. So, there is information feedback between the Texas-OK-NM and Kansas markets in the price discovery process. Changes in the prices in each market impact future changes in the other market. Table 5 uses a double sided arrow to communicate this feedback.

We also see feedback between Texas-OK-NM and Iowa. There is feedback between Kansas and Iowa and Kansas and the futures market. There is feedback between Nebraska and the futures market. The most substantial feedback is between the downstream beef value and the cash markets of Texas-OK-NM, Nebraska, and Iowa.

All other information flows tests indicate one-way relationships. For example, price changes in Texas-OK-NM lead but are not lead by price changes in Colorado and Nebraska. Texas-OK-NM contributes to price discovery in these other markets but the other markets do not contribute significantly to price discovery in Texas-OK-NM. Notice also that changes in live cattle futures prices lead price changes in Texas-OK-NM but not the reverse. Price changes in Kansas lead but are not lead by price changes in Colorado and Nebraska. Kansas price change are led by price changes in the boxed beef composite value. Price changes in Colorado lead price changes only in Nebraska. Colorado is led by Texas-OK-NM, Kansas, and Iowa cash market price changes and price changes in the futures price and beef value. Nebraska also provides very little price discovery. Nebraska is led by Texas-OK-NM, Kansas, Colorado, and Iowa cash markets. Nebraska only displays price discovery through feedback with futures and the beef value. Iowa leads all markets except the ones with which it has feedback: Texas-OK-NM and Kansas and the futures market and beef value.

In summary, Texas-OK-NM and Kansas are strong markets in the price discovery process. The live cattle futures market and the downstream beef value are also strong markets leading price discovery. Iowa is next in terms of contribution. And Nebraska and Colorado are the weakest in terms of contributing to price discovery with Nebraska being the weakest. This final point is troubling. The thickest market in term of volume demonstrates little objective contribution to price discovery. This is an important contribution of this second approach as it is not possible to observe the weakness with Nebraska in the Tomek approach.

These significance tests need to be considered in the context of magnitude of impact. For example, there is feedback between Texas-OK-NM and Kansas. Table 5 reveals past Texas-OK-NM prices reduce the unexplained variance of Kansas price changes by 0.0131 or 1.31% while past Kansas prices reduce the unexplained variance of Texas-OK-NM prices by 0.0271 or 2.71%. The impact of Kansas on Texas-OK-NM is twice as large as the impact of Texas-OK-NM on Kansas. There is also feedback between Texas and Iowa and between Kansas and Iowa. Texas reduces the variance of Iowa by 0.81% and Iowa reduces the variance of Texas by 1.11%. Similarly, Kansas reduces the variance of Iowa by 1.74% and Iowa reduces the variance of Kansas by 1.05%. Iowa has a stronger impact on Texas than it does on Kansas. And Kansas has a stronger impact on Iowa than does Texas. Within the feedback between the beef market and cash markets, we see Texas and Iowa have strong impacts on beef whereas beef has a strong impact on Nebraska.

The strength measures clearly confirm the one-way information flows. Texas-OK-NM and Kansas have 1% to 2% reductions in variances of other cash markets whereas other cash markets reduce the variances of Texas-OK-NM and Kansas by less than ½%. The exception is Iowa. The strength of information flows results also shows inertia within the individual markets. Price changes within Colorado result in further price changes within Colorado. Iowa and Nebraska also display this slow adjustment. Texas-OK-NM cash display much less inertia and make more rapid jumps to higher or lower prices.

The information flows between markets is not linear. The methods used here allow things not to add up. To see this examine the last row in Table 6 is the impact of all other cash markets on the market heading the column. Using Texas-OK-NM, we see that Kansas reduces its variance 2.71%, Colorado

reduces it 0.62%, Nebraska 0.19% and Iowa 1.11% for a total of 4.63%. However, taking these four prices out of the Texas-OK-NM model changes the variance 17.57%. The bottom line is that a little price discovery and price information can go a long way. Individual markets may have little impact on other individual markets. Whereas groups of markets have must larger impacts – larger than the sum of the individuals. This suggestions caution in that price discovery may substantially if multiple individual markets are lost. Returning to the last row of Table 4 we see that Nebraska is most impact by the other four markets. Texas-OK-NM and Colorado are next and similar. Kansas and Iowa are the cash markets least impacted by all other markets. The live cattle futures market and the downstream beef value are the least impacted markets and this is relative to all five fed cattle markets. Futures and the beef markets strongly contribute to price discovery and are the least impacted by prices from cash fed cattle markets.

The issue of impacts not-adding-up is also likely because the results are for the entire sample and are averages of relationships between these markets for the 13 year sample period. The price discovery findings later in the sample period are different from those early in the sample. The next section will look at these changes over time. Nonetheless, it is reasonable that there is strong feedback between Texas-OK-NM and Kansas and also between Nebraska and Iowa. Colorado provides relatively little information in the regional price discovery for cattle. Further, we see a strong price discovery leadership role in the southern plains markets. Nebraska plays a very weak role for its volume and Iowa plays a rather surprisingly strong role. These are the conclusions one draws looking at the results for the entire data period examined. In the next section, we examine these results for subsample and then correlated the subsample results with the changes in cash market volume.

However, next and before the next section, the financial markets research measures of price discovery will be presented. All are presented in Table 7. The first column is the vector of orthogonal complements to α matrix or the common trend weights. The common trend is the sum of the Texas-OK-NM price multiplied by its weight, +0.5043, the Kansas price multiplied by –0.0961, and the remaining five prices by each of their weights and summed. (There is an additional matrix.) All price series and the common trend are graphed in Figure 19. The common trend weights are thus the portion of each price that measures the common trend. Live cattle futures is the largest orthogonal complement, +0.6876, and its relative weight is +0.4728. Live cattle futures is 47.3% of the common trend. Cash markets contribute 50.7% of the common trend. Texas-OK-NM, Iowa, and Nebraska are the largest in descending order. Kansas and Colorado are each less than 1%. The relative weights are in the second column of Table 7. The relative weights of only the cash markets are the third column.

One aspect of the orthogonal complements is counterintuitive but is correct. Kansas and Nebraska both have negative elements. Colorado's is also negative. The negative common trend weights are counterbalanced by larger positive common trend weights associated with a market pair. Kansas and Nebraska are both negative but are offset by Texas-OK-NM and Iowa. This result is observed, not just with the entire sample, but with many subsamples. There are very strong correlations between all the prices but especially between Texas-OK-NM and Kansas and between Nebraska and Iowa. One of the common trend weights for each pair will be negative and the other will be positive and usually larger. This counterintuitive results is a weakness of this method and this data. The cash market prices are so similar that attempting to measure how much each price contributes to the common trend separately

will be imprecise. Groups of measures will be more precise. For example, from the second column we see that Texas-OK-NM and Kansas contribute about 26% of the common trend and Nebraska and Iowa contribute about 23%. When considering just the common trend weights associated with just the cash markets, column three, we see Iowa and Nebraska contribute 46%, Texas-OK-NM and Kansas contribute 52%, and Colorado contributes 2%. These results do change through time and are different in the early subsample from the later subsamples.

The final two columns in Table 4 are correlations between the individual prices and the common trend and correlations between changes in the individual prices and changes in the common trend. All of the fed cattle prices are correlated with the common trend greater than 0.97. Live cattle futures is the highest at 0.9913 and this is driven by the fact that its weight is 47% of the common trend. Thus, these correlations do nothing that are not in the common trend weights. However, they are alternative ways of communicating ideas – the adherence of individual prices to an underlying equilibrium common trend that is the fed cattle market – without relying only on the individual common trend weights. While Kansas and Nebraska have lower weights than Texas-OK-NM and Iowa correlations are very similar.

The correlations of changes provide an alternative to correlations of levels that are clearly very high. The common trend again moves most closely with live cattle futures. The correlation is 0.7494 and again this is due to live cattle futures having the highest weight in the construction of the common trend. Within the cash markets, Texas-OK-NM is most closely correlated with the common trend at 0.5696 and thus contributes the most of the cash markets to price discovery. Iowa is next at 0.5676, Kansas is third at 0.4580, Colorado is fourth at 0.3807, and Nebraska is last with a correlation of 0.3741. Thus, there appear to be two distinct regions that contribute to cash fed cattle price discovery and they are the northern plains markets of Iowa and Nebraska and the southern plains market pair of Texas-Oklahoma-New Mexico and Kansas. Within each pair, there is a strong and weak market. Texas-OK-NM and Iowa are strong. Kansas and Nebraska are weak. Over the entire sample, Colorado plays a role similar to Nebraska.

Rolling Subsample Results Related to Cash Market Volume

The next step is to examine how these objective measures of price discovery change with changing cash volumes in the individual markets. We will be looking to see how price discovery measures change with changing volumes of cash trade. Econometric models are used to explain the price discovery results as a function of the cash volume in each regional market. This is the approach used by Goodwin and Schroeder to examine regional market price behavior. The work reported here is the first to examine price discovery measures and market volume relationships.

The strength of information flows show a clear relationship with cash market volume. An example will be provided first and then general discussion. Figure 20 graphs the regression of cash market volume versus the reduction in error variance that measures the strength of information flow. The market is Texas-OK-NM. There is a positive slope between cash volume and strength of price discovery and it has modest declining curvature. The more cash volume there is then the more impact that price changes in Texas-OK-NM have on other cash markets and this is increasing at a slightly decreasing rate. Of course, the cash volume is trending downward in Texas and the result communicates that Texas-OK-NM no longer plays a significant role in price discovery. With almost not cash volume then there is no price

discovery. The dash lines indicate the 90% confidence interval around the regression line. The regression line itself approaches zero price discovery with zero cash market volume. The lower confidence bound indicates that price discovery is insignificantly different from zero at 7,000-8,000 head per week.

Figure 21 displays results for all five regional fed cattle markets and that includes the same graphic for Texas from the prior figure – without the upper confidence interval bound as it is not needed. All of the regression lines have the same slope but different intercepts. The data does not disagree with this assumption with one notable exception. Figure 22 shows the relationship between strength of price discovery and cash market volumes for all of the regional markets when all the slopes and intercepts are allowed to be different. The statistics indicate that intercepts are significantly different and that the slopes are generally not. Close examination of the figure shows that Nebraska might be – and that is the conclusion of the data – a modest significant difference. Colorado's slope however is statistically different. The bottom line is we can draw conclusions from Figure 21 and that we should make sure they do not disagree substantially with what is communicated on Figure 22. The other bottom line is that there is clearly a relationship between volume and price discovery.

In the models summarized in these three figures, there are strong average differences across markets. The relationship between information flows and cash market volume has different mean effects – the intercepts are different for each regional market – while the relationship between the volume of cash trade and strength of information flows is positive. As the volume of cash trade in a region shrinks the strength of information flows – the impact that price changes in that market impact other markets – lessens. The relationship between volume and information flows is allowed to be different for each market. But many are similar. For example, the relationship between volume of cash trade and strength of price discovery is similar between Texas-OK-NM, Kansas and Iowa. Colorado is different from the group and Nebraska may be.

The strongest relationship between volume of cash trade and price discovery occurs with Colorado. The result is due to Colorado contributing substantially to price discovery when it had cash market volume early in the sample. And Colorado contributed to price discovery in cash fed cattle markets in those periods.

There is a weak relationship between volume of cash trade and strength of price discovery for Iowa. The regression coefficient is similar to other markets but rather insignificant. This result is likely due to Iowa having very little change in cash trade volumes. If the volume of cash trade does not change then it cannot explain. Iowa contributes strongly to the entire sample periods price discovery results and consistently has strong results – given the modest volume which is second lowest with Colorado having the smallest cash marketings. The insignificant relationship is seen by how far the dashed line is from the solid line.

Changes in the strength of price discovery were examined over time. The price discovery provided by cash markets lessens over time. That is unless time and cash market volume are both used to explain the strength of price discovery. In that case, time period explains little and volume of cash trade does the work in the econometric models. Thus, price discovery as measured by price changes in leading and following markets is not shrinking, or expanding, in cash markets. Price discovery is related to the

market volume – allowing for inherent average differences in the regional markets. And the higher the cash market volume the more cash markets contribute to the strength of price discovery. But some markets contribute strongly and others are weak with the same volume.

There is less price discovery occurring in regional cash markets. And there is no evidence here that, with the shrinking cash trade, there is improved price discovery in the volume that is left. There is no evidence that what is left for cash markets is working harder. Cash markets are different and contribute less with less cash trade. For example, Texas-OK-NM and to a limited extent Kansas provided a lion's share of the cash market price discovery early in the sample period. This is seen in the overall results and in the rolling subsamples. However, the southern plains markets late in the sample provide little price discovery. Is some other regional market doing the work? Have the northern plains markets taken over this role? There is no evidence of that. Nebraska is a weak contributor to price discovery relative to Iowa and Nebraska's role does not improve with time. The only evidence of improved contribution to price discovery is with the live cattle futures market. That market is doing relatively more price discovery work. It has always been important, its magnitude of contribution to price discovery is not increasing, but it is relatively more important as the cash volume thins.

The relationships between the financial markets research measures and cash market volume are much less interesting. The measures of price discovery used by agricultural economics research tell a clear, logical and reasonable story of the relationship between volume of cash trade and strength of price discovery. The same is not true for the financial markets research measures.

The variation in cash market volumes explains no variation in the common trend weights and the relative weights created there from. The common trend weights, the relative weights, and the relative cash weights do not move systematically with changes in regional cash market volumes. (These measures are reported in Figures 23-25.) The Texas-OK-NM tends to be the highest while Colorado is the lowest. But there is too much variability among the other markets to make any general statements. The volume of cash trade – either a single measure or allowing different measures for different regions – is never statistically significant. The only relationship that is apparent in the models suggests a pattern through time. The cash market weights are the highest early in the sample, moderate in the middle of the sample, and then increase again late in the sample. It is this result alone that suggests cash markets are doing more price discovery work as the cash market thins. This result may be illustrating improved market integration in that the markets move more closely with each other and the common trend late in the sample. As cash markets have thinned then buyers and sellers pay more attention to and are influenced more by prices in all markets. Similarly, there is also improved technology, shrinking communications costs, and changes in the people that are doing the cash market trading. This appears to be the only positive result regarding the quality of price discovery.

When the weights and alternative measures of price discovery over time we see the following. Texas-OK-NM is the most important market and is the most important southern market. Kansas is a weaker market. Iowa is the second most important market and the most important northern market. Nebraska is also a weak market. Considering the northern and southern market pairs – that negative weights are matched by a positive weight – then the following is found. The pair of southern markets contribute the most to price discovery followed closely by the northern market pair. Colorado is a distant fifth.

However, while cash market weights increase later in the sample few of these results are clearly significant. Texas-OK-NM and Iowa are the most significant. Colorado is the least.

The correlation results are the interesting and support the market pair interpretation. (The two correlations are reported in Figures 26 and 27.) Kansas and Texas-OK-NM follow the common trend most closely. In recent subsamples these correlations are above 0.9750. Nebraska is next and the correlation is roughly 3% behind the southern market pair. Iowa is next and is 5% lower than Nebraska. Thus, the southern market pair follows the common trend most closely. The northern market pair is next, less precise and Iowa is the weakest of the four regions. Again Colorado is a distant fifth with a correlation of about 0.8750. Nebraska and Kansas appear to be soft markets in terms of contributing to price discovery until they are used with information from the other market within their pair and then their contribution is clearer.

Changes in Texas-OK-NM and Kansas prices are correlated the highest with changes in the common trend. The correlations are 70% and 66%. Nebraska and Iowa are next with correlations of 65-64%. The correlation for Colorado is about 40%. Again, the southern pair is the strongest market pair followed by the northern pair. And even late in the rolling subsample the southern markets contribute to and follow the common trend. The northern markets contribute to and follow the common trend but less than the southern pair. Based on these measures the northern markets are not doing more price discovery.

Making use of the correlations avoids some of the problems associated with interpreting individual weights. These correlations are likely the best of the financial markets research measures. Any of the weights measures have numerical difficulties that limit their individual interpretation but work fine within the group of seven markets.

What Cash Volume is Needed?

The models can answer the question: What level of cash trade is need for price discovery to occur in the different USDA AMS regional markets? The answers to this question can be used to drive decisions of what to do about the issue. If industry or government is interested in addressing the issue of, “How thin is too thin?” then the models can provide predictions for at what level of cash trade does price discovery occur. Further, the predicted volumes need to also recognize the confidence interval for the prediction. This information is distinctly different from the Tomek approach as it considers the objective price discovery measures and not just the sampling error.

Any cash trade in Texas-OK-NM contributes to price discovery. However, 90% confidence requires 7,000 head per week. At this level of cash trade then historically TX-OK-NM has contributed to price discovery. Kansas needs to trade 2,000-7,000 head per week but 90% confidence requires 14,000 head per week. Nebraska needs to trade 7,000-17,000 head per week and 90% confidence requires 17,000-26,000 head per week. Nebraska contributes to price discovery but requires higher volumes of cash trade than Texas-OK-NM or Kansas. Any cash trade in Iowa contributes to price discovery but 90% confidence requires 3,000-10,000 head per week. And any volume of cash trade in Colorado contributes to price discovery but 90% confidence requires 2,000-3,000 head per week. Iowa is a relatively strong market. Texas-OK-NM and Kansas are a market pair. And Iowa and Nebraska are a market pair. Price discovery is strongly provided by Texas-OK-NM in the southern plains and Iowa in the northern plains.

Colorado contributes relatively little in total to price discovery but Colorado appears to be unique and it is likely that this is due to being the market furthest from the other four markets.

These lower limit numbers are useful but unsatisfying. These recommendations are what is needed to go from insignificant to significant price discovery. It says nothing about the robustness of price discovery. The rolling subsamples results reveal that historically each market has had an information flow impact between 5-10%. Thus, in Figures 21 and 22 envision a horizontal line between 5% and 10% on the vertical axis – 7.5% is reasonable. Where this horizontal line intersects the colored regression lines will indicate a volume needed to generate a level of price discovery consistent with history. Specifically, Texas-OK-NM needs approximately 23,000-25,000 head traded per week. Kansas requires 35,000-40,000 head per week. Colorado requires 8,000-12,000 head per week. Nebraska requires 38,000 head per week. Iowa requires 13,000-17,000 head per week. Similarly, 5% could be used as it is also reasonably strong contribution to price discovery.

Cash volume is clearly related to agricultural economics research measures of price discovery. And less cash volume or a thinning cash market implies less price discovery. The measures used in financial markets research are not as pessimistic. Texas-OK-NM, Iowa, Kansas, and Nebraska are important determinants of the cattle and beef market common trend. Colorado is much less important. Likewise, Texas-OK-NM, Kansas, Nebraska, and Iowa correlate most closely with the common trend and changes in the common trend. Texas-OK-NM, Kansas, Nebraska, and Iowa well-represent the price of fed cattle. Whereas, Colorado less so. But we simply cannot do a similar prediction exercise of what volume generates strong weights or correlations.

Thus, even with substantial declines in cash market trade in important regional markets the resulting prices well represent what is the fed cattle market. These historically important markets determine the market trend. However, these historically important markets are doing less price discovery work. That has transferred to the live cattle futures market. Cash fed cattle markets in 2014-15 are doing half of the price discovery work that they did when MPR was implemented. And some important markets are doing none. The southern plains markets contribute almost nothing to price discovery. Northern plains markets have taken over that role. But the northern plains continue to do the work that they have always done. They are not doing more work. The more work has transferred to the futures market.

What's left is more integrated across markets and markets follow the common trend. But what's left is doing less price discovery work in that what's left of cash markets do not lead price changes – rather they largely follow price in the futures market.

Summary

The objective price discovery results tell a clear story with some complications in the details. First, the five USDA AMS regional cash markets perform less price discovery over time. This is related to the shrinking cash trade and not simply passage of time. There is less cash trade in historically important regional markets. Less cash trade results in less price discovery work being conducted. This is revealed in the linkages between price changes across markets – there are leading markets and following markets. However, it is counter balanced by the common trend results. The weights of the common trends weaken over time but then strengthen later in the sample. The fed cattle markets as a whole appear to be more closely related.

Second, there is different levels of price discovery performed by the regional markets that is not related to volume. All price discovery in cash markets is not related to volume. There are strong markets and weak markets. But as the volume shrinks all of the regional markets have a clear reductions in the amount of price discovery that is done and most of the markets have similar reductions in the amount of price discovery performed.

Further, price discovery declines at a modestly increasing rapid rate as cash market volume declines. The useful twist on this relationship is that small amounts of cash trade can result in significant price discovery and that further increases in cash trade likely do not result in proportionally more price discovery. The price discovery services of the regional cash fed cattle markets appear to face diminishing returns. More cash trade is better but has a smaller impact.

Third, it is also very clear that there is more price discovery is being done by the live cattle futures market. As the volume traded in cash markets has shrunk then the market looked to for information is the live cattle futures market. Therefore, this market performs more price discovery as cash markets perform less. The futures market has always performed important price discovery services – it is the forward looking market. But this role has increased with declining cash trade. Price changes in live cattle futures lead price changes in regional cash market and the impact from futures to cash markets is greater as cash volumes shrink. It is also the case that changes in cash prices lead changes in nearby futures prices but much less so with diminished cash market volumes and the strength of the impact of cash on futures is less. The downstream boxed beef markets are important but perform relatively little price discovery that spills into the fed cattle markets. Changes in boxed beef valuations lead to changes in cash fed cattle prices but the strength of the information flows is modest and it does not increase over time.

Fourth, all of the regional cash fed cattle markets have contributed to price discovery. There is no market that provides no information. There are markets that are historically important sources of price discovery. This is seen in the results. Texas-OK-NM, Kansas, Iowa, and Nebraska are all important to the price discovery process. But even the historically small cash volume markets are periodically important. Periodically, price discovery is significant in Colorado and in the other weaker markets: Kansas and Nebraska. The results do not lead to the conclusion that USDA AMS could eliminate reporting for a regional market.

How thin is too thin? It depends on the regional market. It depends on if significant or robust price discovery is the objective. There is not a blanket recommendation that covers all regional markets.

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Table 1: Unit Root Tests of Price Series.

Market Price	Rho	P-Value	Tau	P-Value
Texas	-1.21	0.8656	-0.43	0.9012
Kansas	-1.50	0.8356	-0.51	0.8869
Colorado	-1.72	0.8107	-0.58	0.8724
Nebraska	-1.54	0.8316	-0.55	0.8778
Iowa	-1.10	0.8764	-0.41	0.9055
Nearby Futures	-0.32	0.9393	-0.12	0.9453
Downstream Beef Value	-7.28	0.2571	-1.71	0.4282

All tests fail to reject the null hypothesis of nonstationarity. All of the price series are nonstationary.

Table 2: Johansen Rank Tests for Order of Cointegration.

Max Test				Trace Test			
H_0: Rank = r	H_1: Rank = r+1	Test	5% CV	H_0: Rank = r	H_1: Rank > r	Test	5% CV
0	1	102.174	45.28	0	0	409.207	132.00
1	2	86.7558	39.37	1	1	312.340	101.84
2	3	83.7775	33.46	2	2	227.026	75.74
3	4	60.8934	27.07	3	3	143.199	53.42
4	5	40.5097	20.97	4	4	84.0471	34.80
5	6	33.4946	14.07	5	5	40.3275	19.99
6	7	0.0016	3.76	6	6	2.6405	9.13

Both tests suggest the 7 variable system has a rank of 6.

Table 3: Estimates of Correction Parameters α.

	1 (TX–BV)	2 (KS–BV)	3 (CO–BV)	4 (NE–BV)	5 (IA–BV)	6 (CF–BV)
TX	-0.0276	0.1787	0.1662	0.0199	**-0.4614**	**0.1868**
KS	0.0390	**0.1617**	**-0.3873**	0.0013	0.0726	**0.1624**
CO	**-0.5598**	0.1946	**0.2717**	0.0398	**-0.1371**	**0.2403**
NE	0.0058	**0.2611**	-0.0109	**-0.2214**	-0.0380	0.0976
IA	-0.0085	**-0.1431**	-0.0784	0.0993	**0.1103**	0.0846
CF	-0.0648	0.1380	-0.0884	**-0.1239**	**0.2477**	-0.0828
BV	**-0.0653**	0.1446	0.0424	**0.1590**	-0.0133	0.0271

Negative estimates imply stabilizing adjustments and positive number imply destabilizing. The largest negative and positive are bolded.

Table 4: Significance Levels of Causality Tests or Information Flows from the Market Heading the Row to the Market Heading the Column.

→	TX	KS	CO	NE	IA	CF	BV
TX		**0.0258**	**0.0201**	**0.0033**	*0.1265*	0.3388	**0.0219**
KS	**0.0002**		**0.0243**	**0.0050**	**0.0062**	**0.0004**	0.6524
CO	0.2208	0.5033		**0.0365**	0.3823	0.7708	0.8639
NE	0.7144	0.9802	0.4942		0.3633	**0.0388**	*0.1769*
IA	**0.0481**	**0.0592**	**0.0921**	**0.0042**		**0.0049**	**0.0672**
CF	**0.0001**	**0.0670**	*0.1301*	**0.0275**	0.4172		**0.0013**
BV	**0.0001**	**0.0003**	**0.0001**	**0.0225**	*0.1598*	**0.0869**	

Strong significance (≤10%) is bolded. Modest significance (10-20%) is italicized and underlined. Insignificant relationships are not marked-up.

Table 5: Information Flows Between Markets.

	TX	KS	CO	NE	IA	CF	BV
TX	–	←→	→	→	←→	←	←→
KS		–	→	→	←→	←→	←
CO			–	→	←	←	←
NE				–	←	←→	←→
IA					–	→	←→
CF						–	←→
BV							–

Large black arrows indicate strong significance: ≤10% level. Small red arrows indicate modest significance: 10-20% level.

Table 6: Strength of Information Flows from the Market Heading the Row to the Market Heading the Column Measured by Percent Reduction in Error Variance.

→	TX	KS	CO	NE	IA	CF	BB
TX	0.0037	0.0131	0.0138	0.0193	0.0081	0.0044	0.0136
KS	0.0271	0.0351	0.0133	0.0181	0.0174	0.0256	0.0023
CO	0.0062	0.0033	0.1214	0.0120	0.0043	0.0048	0.0010
NE	0.0019	0.0003	0.0034	0.0631	0.0045	0.0118	0.0070
IA	0.0111	0.0105	0.0091	0.0186	0.0764	0.0181	0.0101
CF	0.0112	0.0098	0.0072	0.0220	0.0058	0.0115	0.0271
BB	0.0060	0.0077	0.0111	0.0178	0.0045	0.0068	0.0087
All Other Cash	0.1757	0.1686	0.1735	0.1975	0.1689	0.1148	0.1090

Table 7: Orthogonal Complements, Relative Market Weights, Relative Cash Market Weights, Correlations of the Common Trend with Each Price in Levels, Correlations of changes in the Common Trend with Changes in Each Price.

	Orthogonal Complements	Relative Weights	Relative Cash Weights	Correlation Levels	Correlation Differences
TX	0.5043	0.2543	0.5013	0.9835	0.5696
KS	-0.0961	0.0092	0.0182	0.9814	0.4580
CO	-0.0977	0.0095	0.0188	0.9796	0.3807
NE	-0.2827	0.0799	0.1575	0.9745	0.3741
IA	0.3928	0.1543	0.3041	0.9769	0.5676
CF	0.6876	0.4728		0.9913	0.7494
BB	-0.1412	0.0200		0.9473	-0.2656

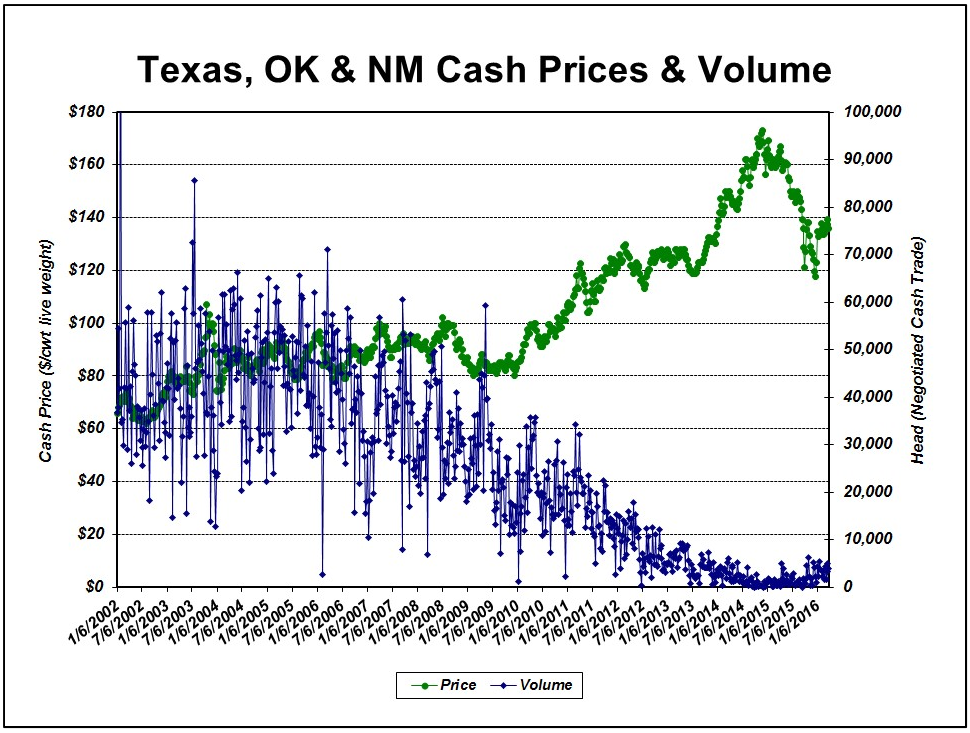

Figure 1: Negotiated Cash Volume and Price for Texas-Oklahoma-New Mexico since the Implementation of Livestock Mandatory Price Reporting.

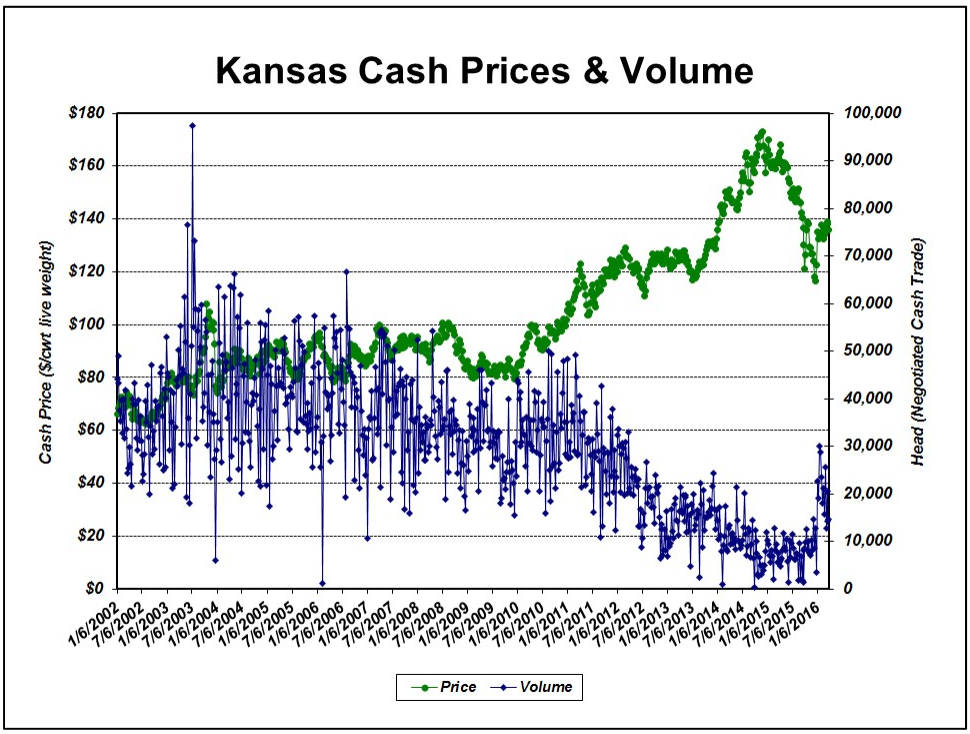

Figure 2: Negotiated Cash Volume and Price for Kansas since the Implementation of Livestock Mandatory Price Reporting.

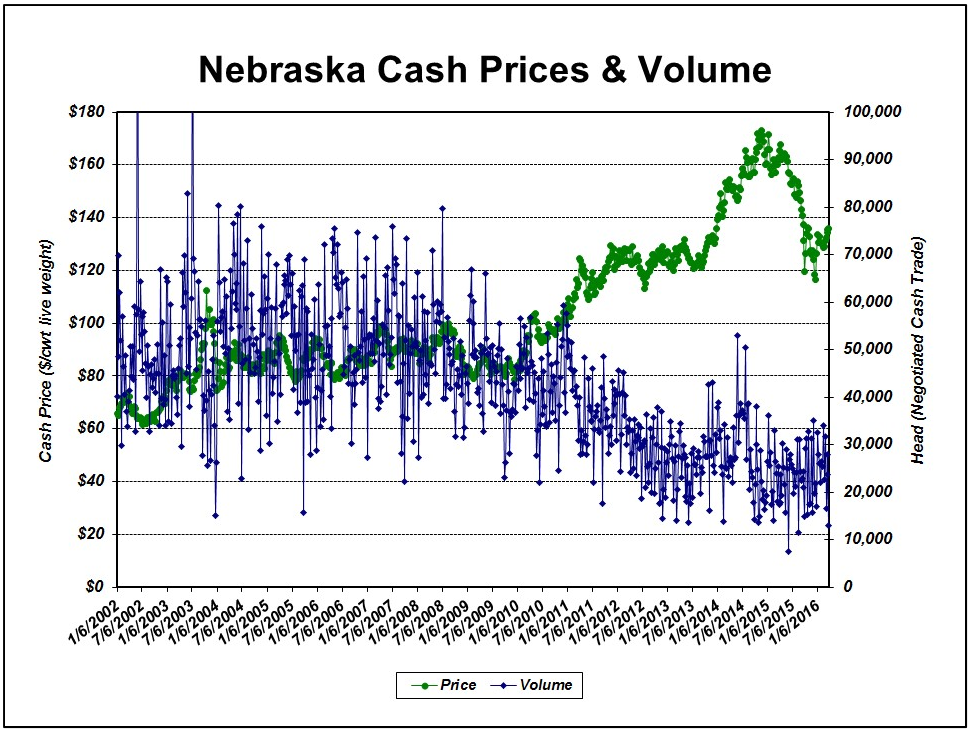

Figure 3: Negotiated Cash Volume and Price for Nebraska since the Implementation of Livestock Mandatory Price Reporting.

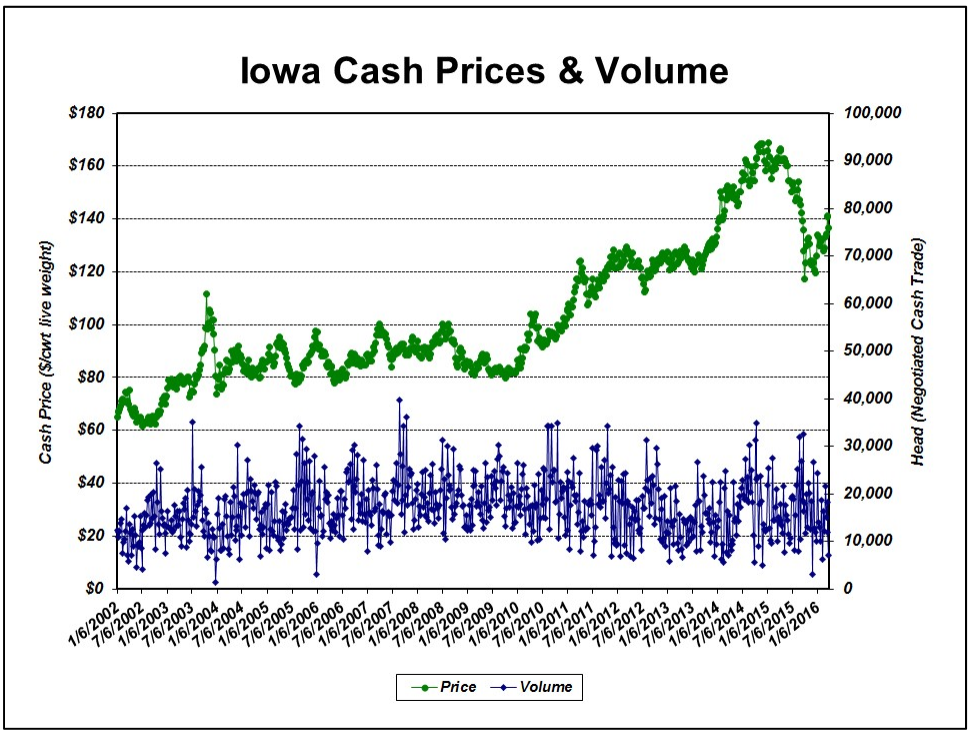

Figure 4: Negotiated Cash Volume and Price for Iowa since the Implementation of Livestock Mandatory Price Reporting.

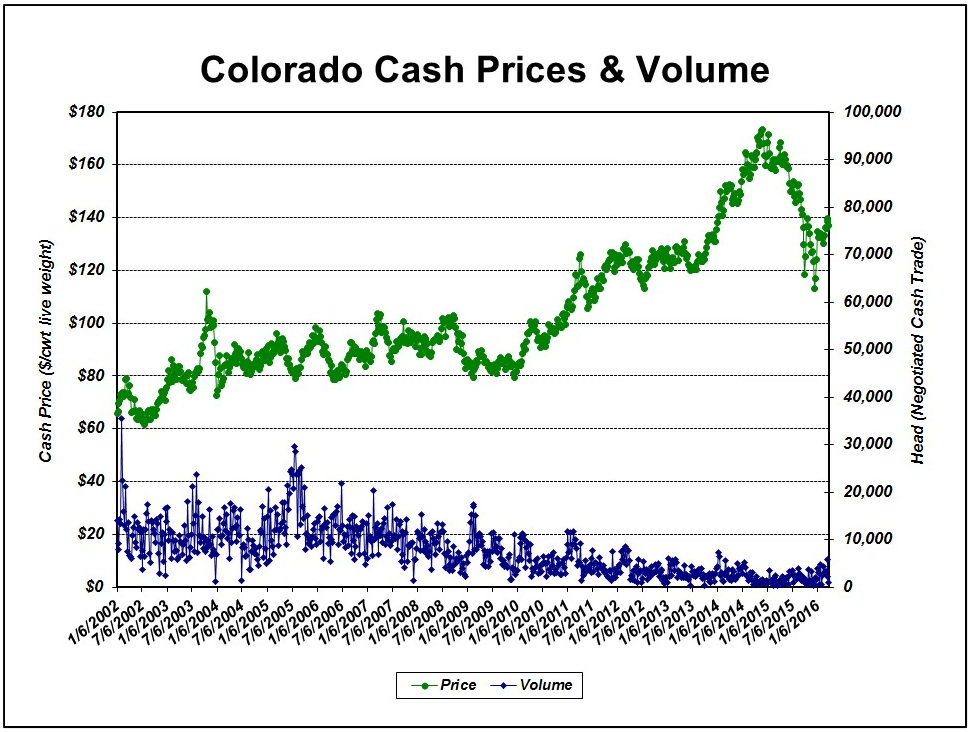

Figure 5: Negotiated Cash Volume and Price for Colorado since the Implementation of Livestock Mandatory Price Reporting.

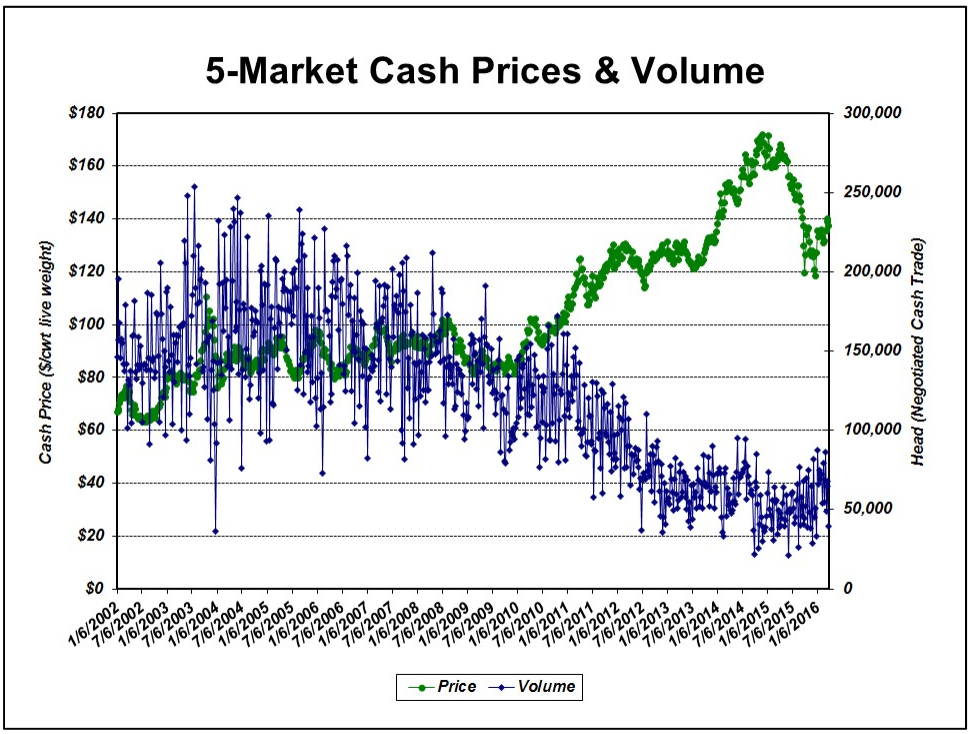

Figure 6: Negotiated Cash Volume and Price for the Five USDA AMS Reporting Regions since the Implementation of Livestock Mandatory Price Reporting.

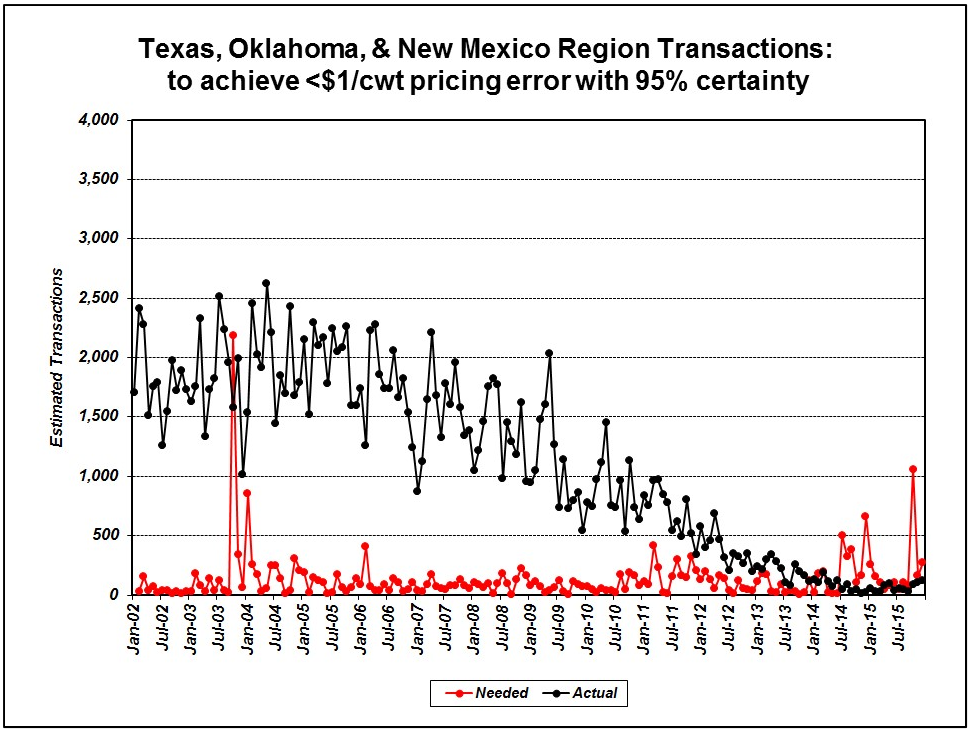

Figure 7: Estimated Actual Transactions and Transactions Needed to achieve <$1/cwt Pricing Error with 95% Probability for Texas-Oklahoma-New Mexico.

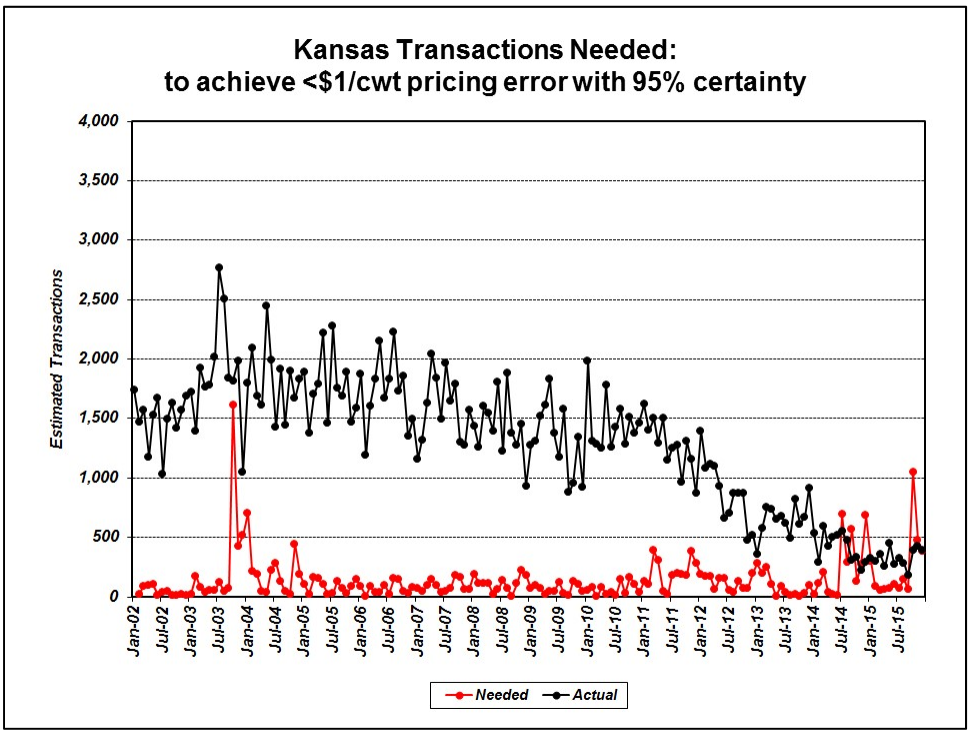

Figure 8: Estimated Actual Transactions and Transactions Needed to achieve <$1/cwt Pricing Error with 95% Probability for Kansas.

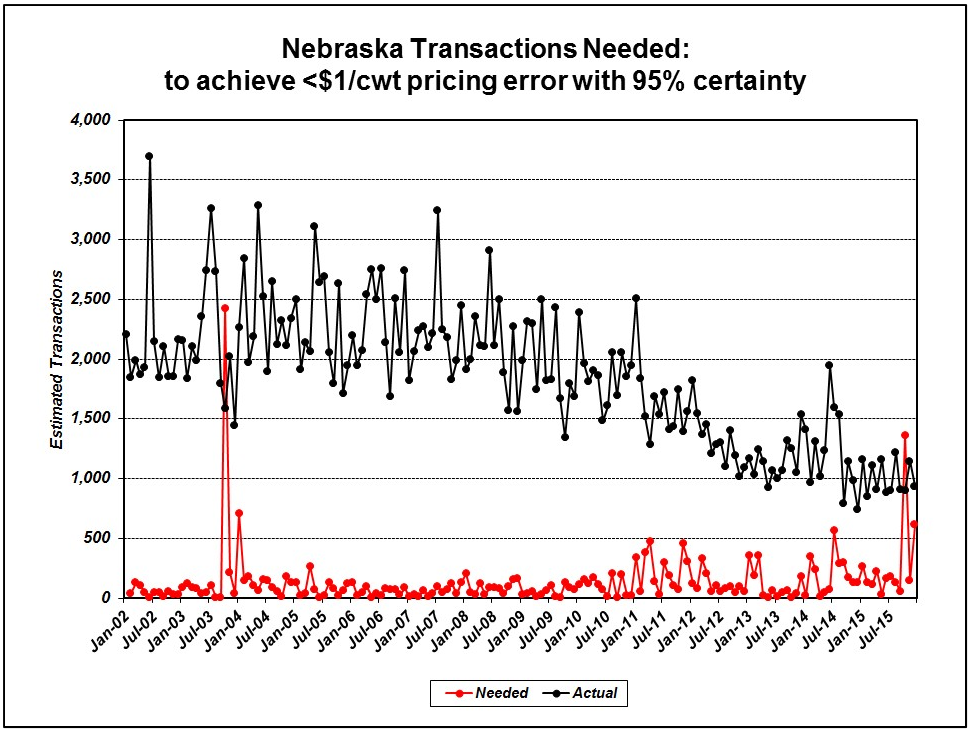

Figure 9: Estimated Actual Transactions and Transactions Needed to achieve <$1/cwt Pricing Error with 95% Probability for Nebraska.

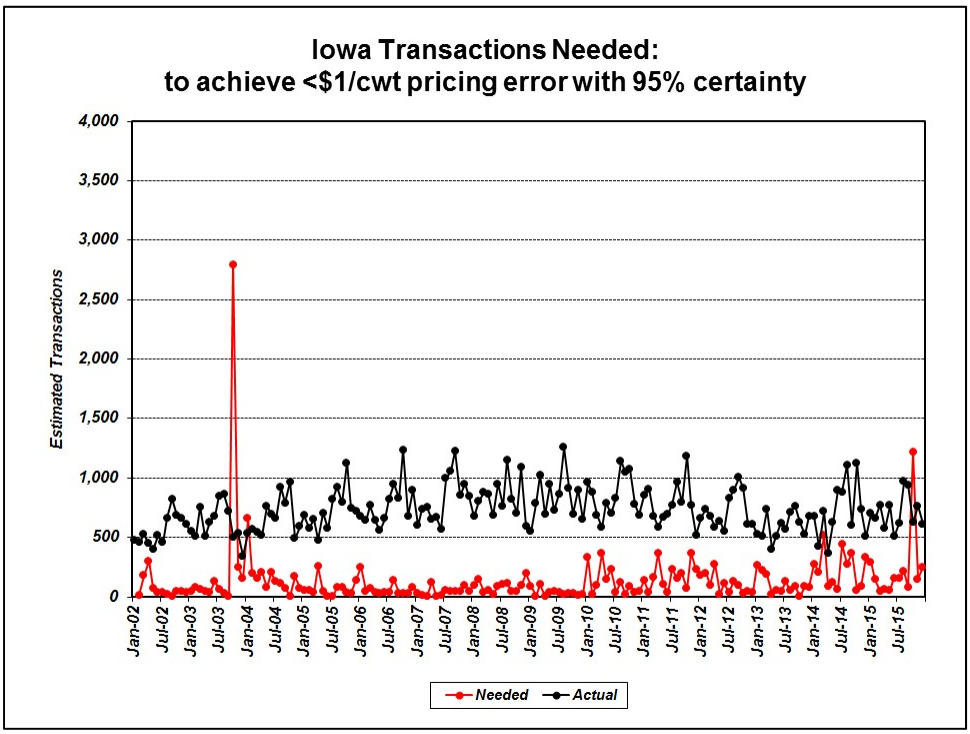

Figure 10: Estimated Actual Transactions and Transactions Needed to achieve <$1/cwt Pricing Error with 95% Probability for Iowa.

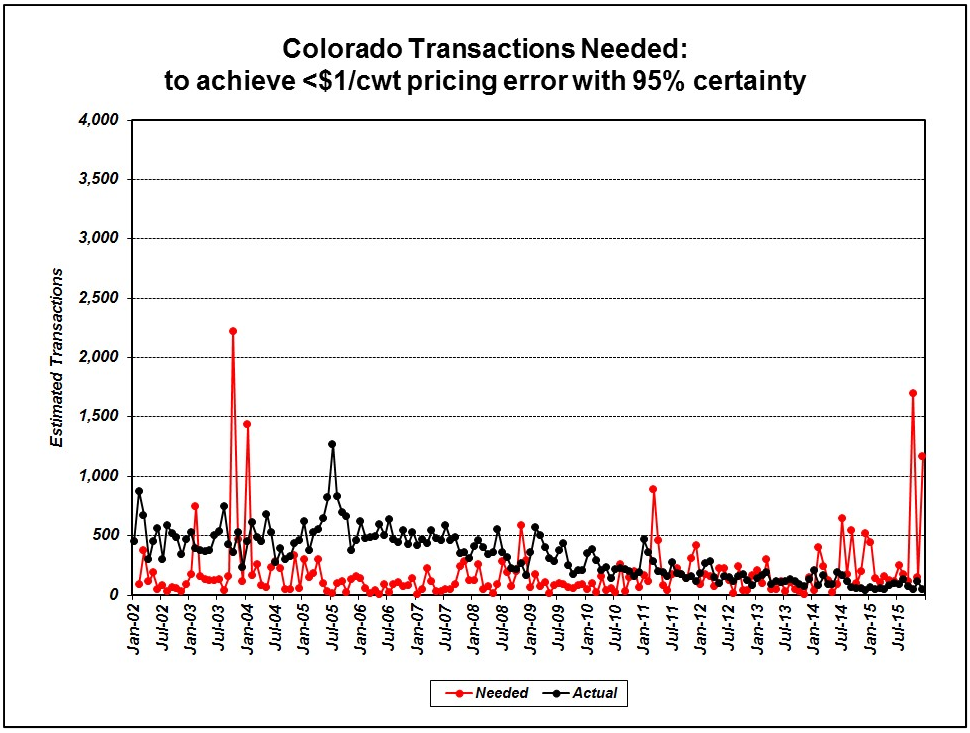

Figure 11: Estimated Actual Transactions and Transactions Needed to achieve <$1/cwt Pricing Error with 95% Probability for Colorado.

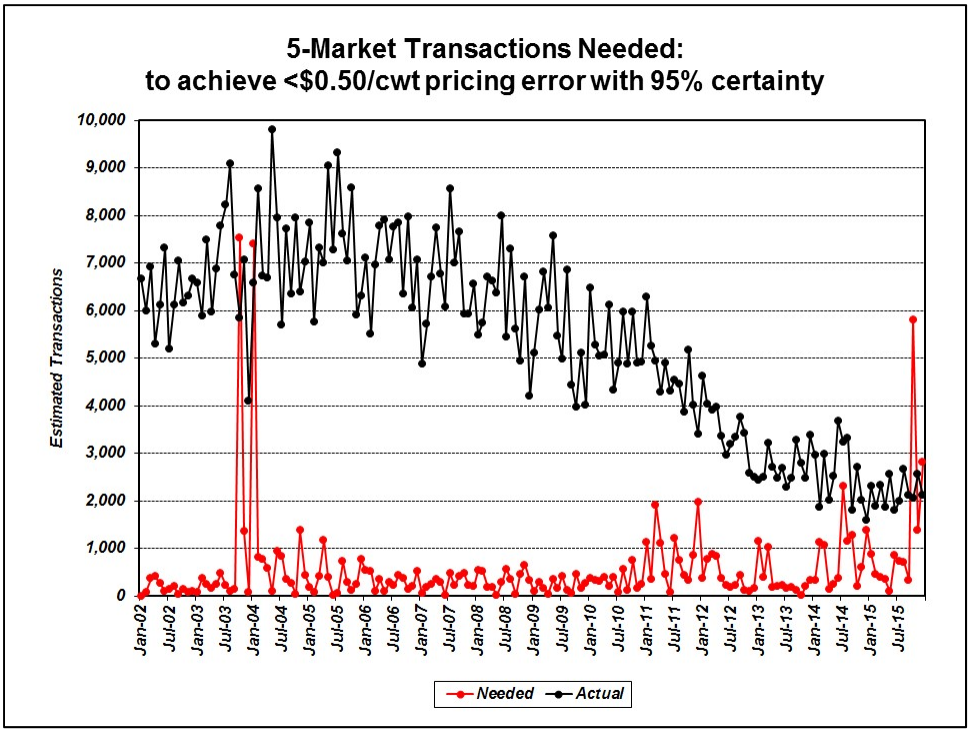

Figure 12: Estimated Actual Transactions and Transactions Needed to achieve <$1/cwt Pricing Error with 95% Probability for the 5-Market Weighted Average.

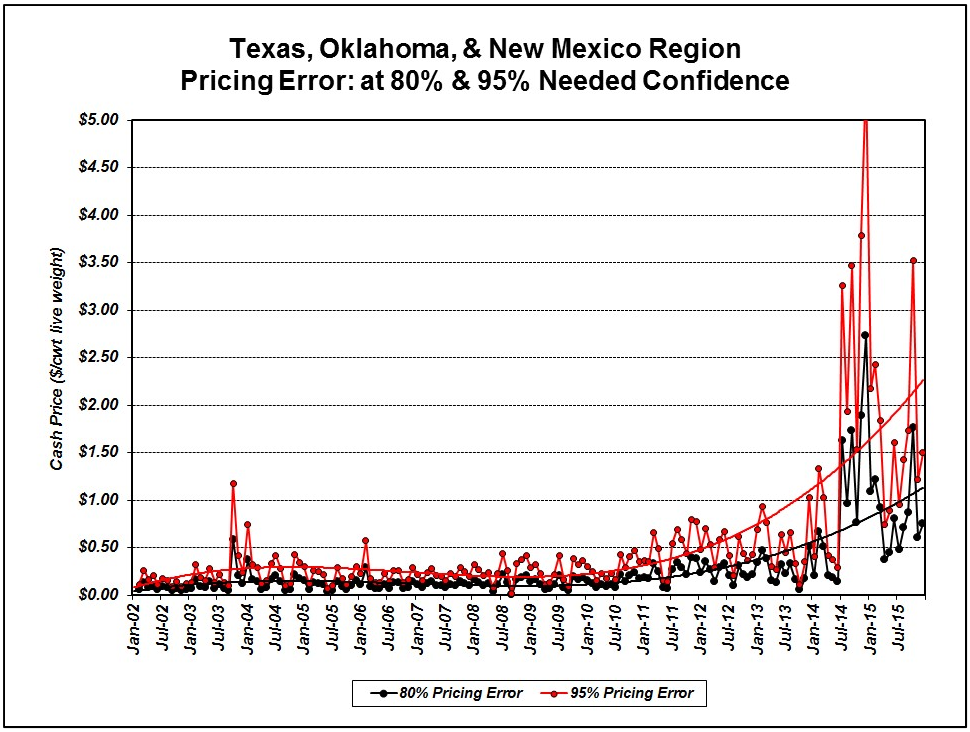

Figure 13: Pricing Error Given the Estimated Actual Number of Transactions for a 95% and 80% Probability for Texas-Oklahoma-New Mexico.

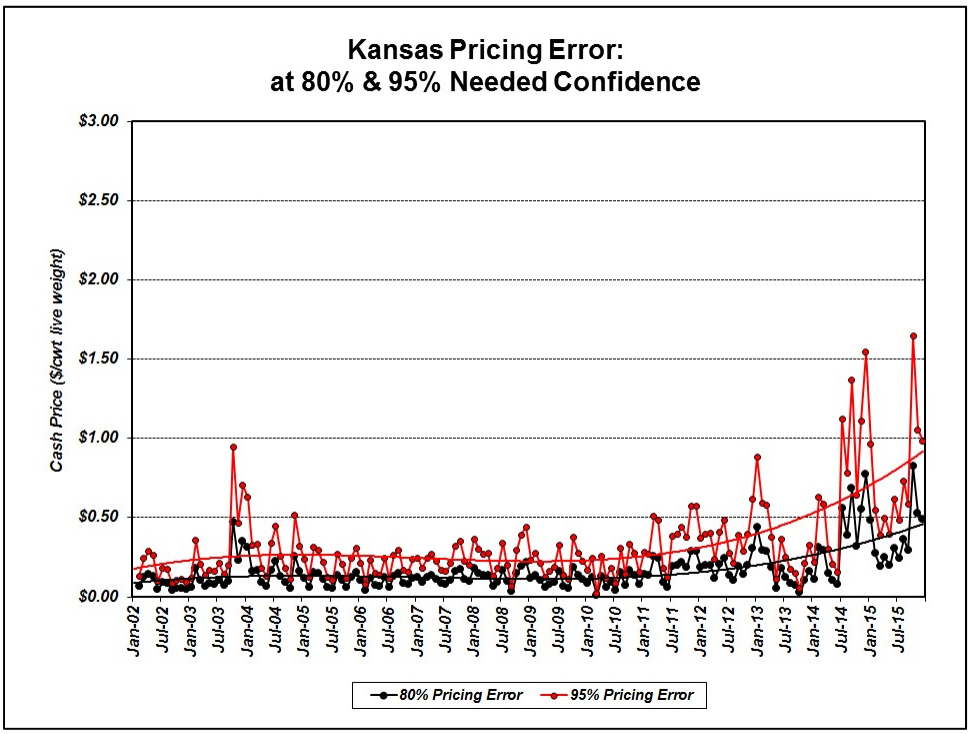

Figure 14: Pricing Error Given the Estimated Actual Number of Transactions for a 95% and 80% Probability for Kansas.

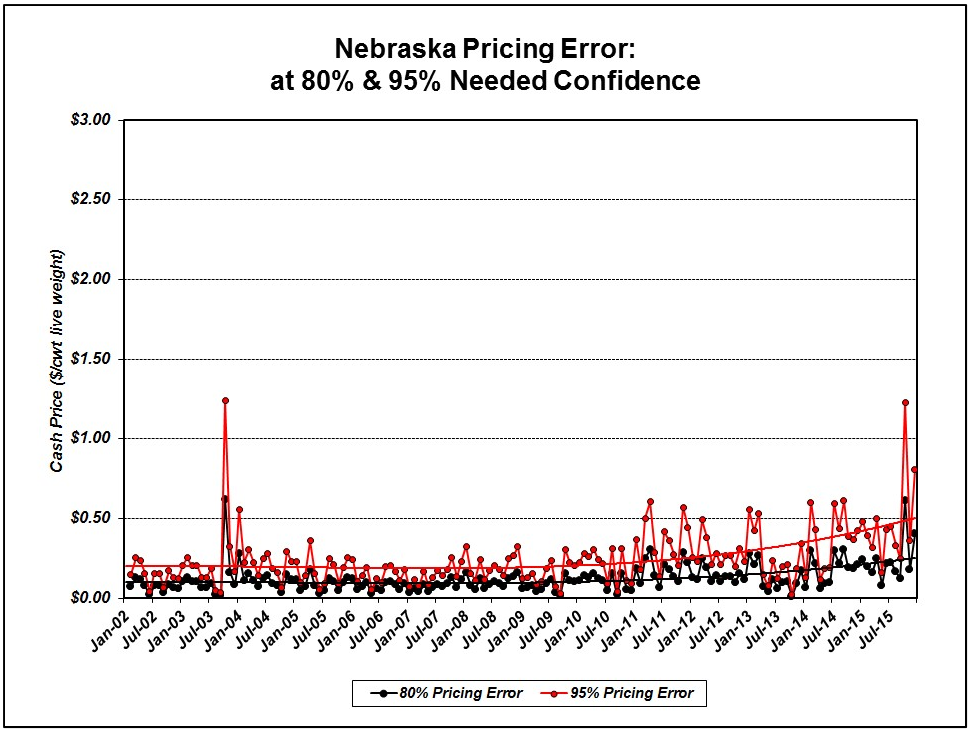

Figure 15: Pricing Error Given the Estimated Actual Number of Transactions for a 95% and 80% Probability for Nebraska.

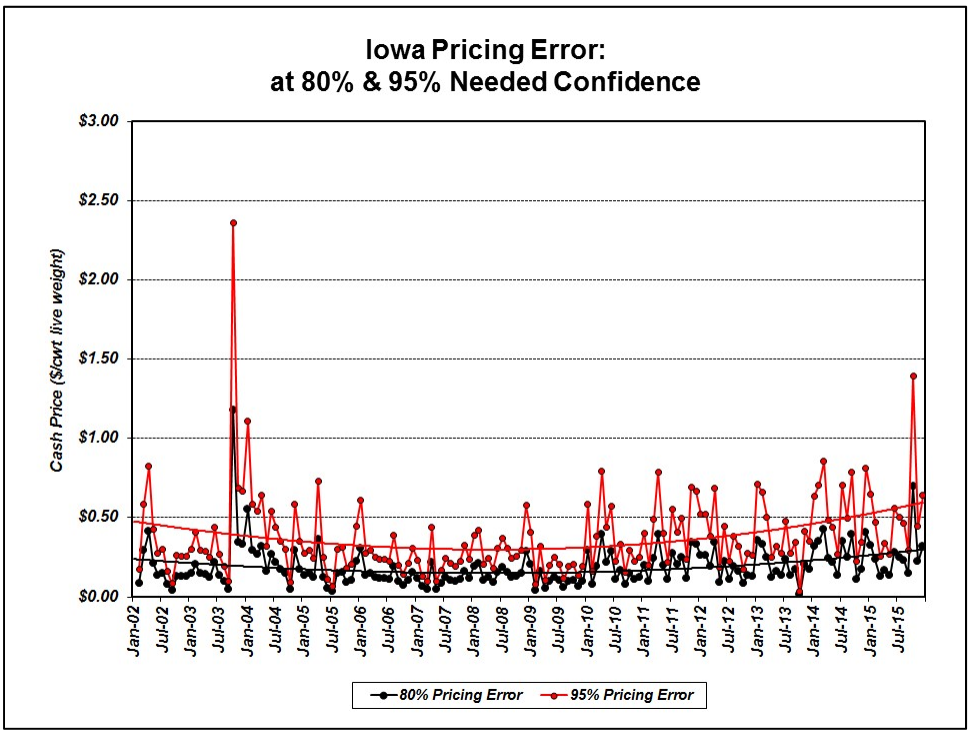

Figure 16: Pricing Error Given the Estimated Actual Number of Transactions for a 95% and 80% Probability for Iowa.

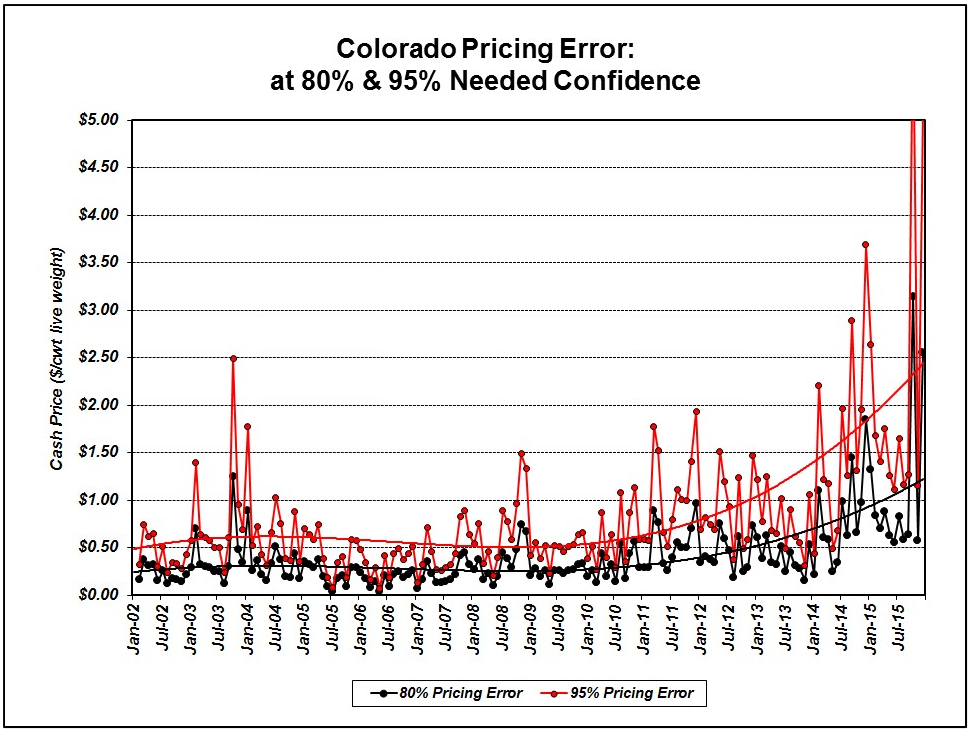

Figure 17: Pricing Error Given the Estimated Actual Number of Transactions for a 95% and 80% Probability for Colorado.

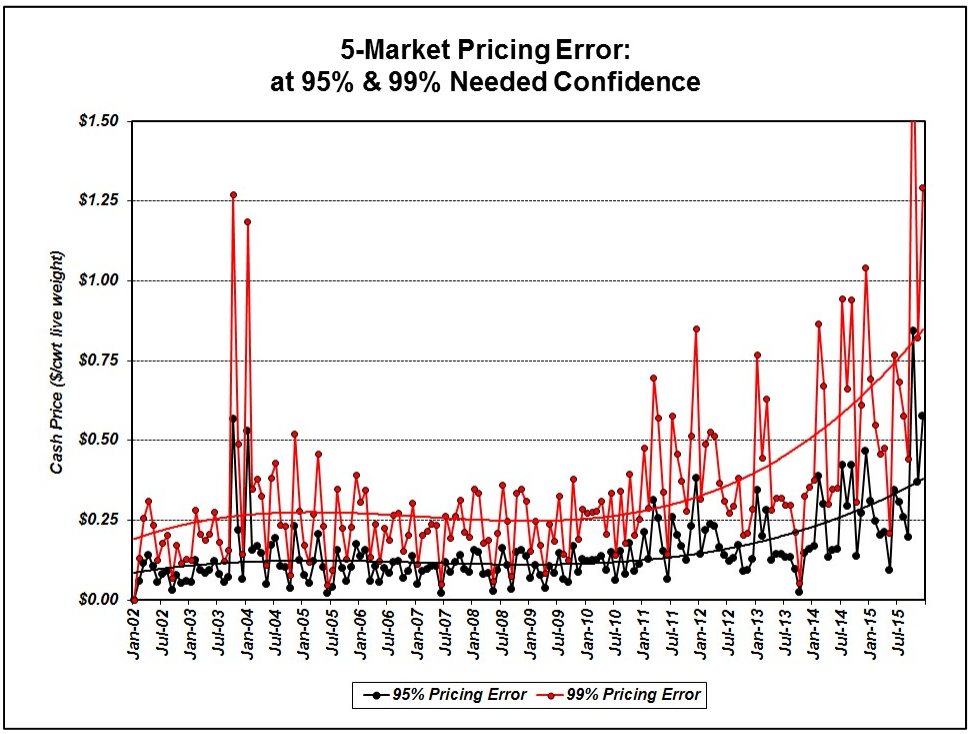

Figure 18: Pricing Error Given the Estimated Actual Number of Transactions for a 95% and 99% Probability for the 5-Market Weighted Average.

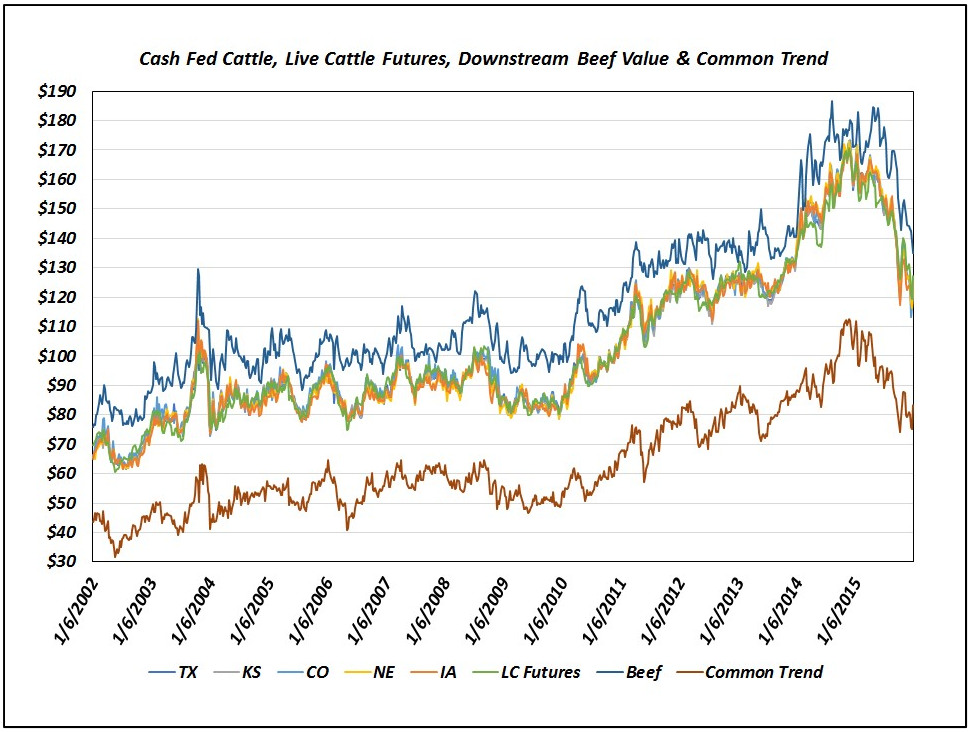

Figure 19: Regional Fed Cattle Market Prices, Live Cattle Futures Prices, Downstream Beef Value, and the Common Trend.

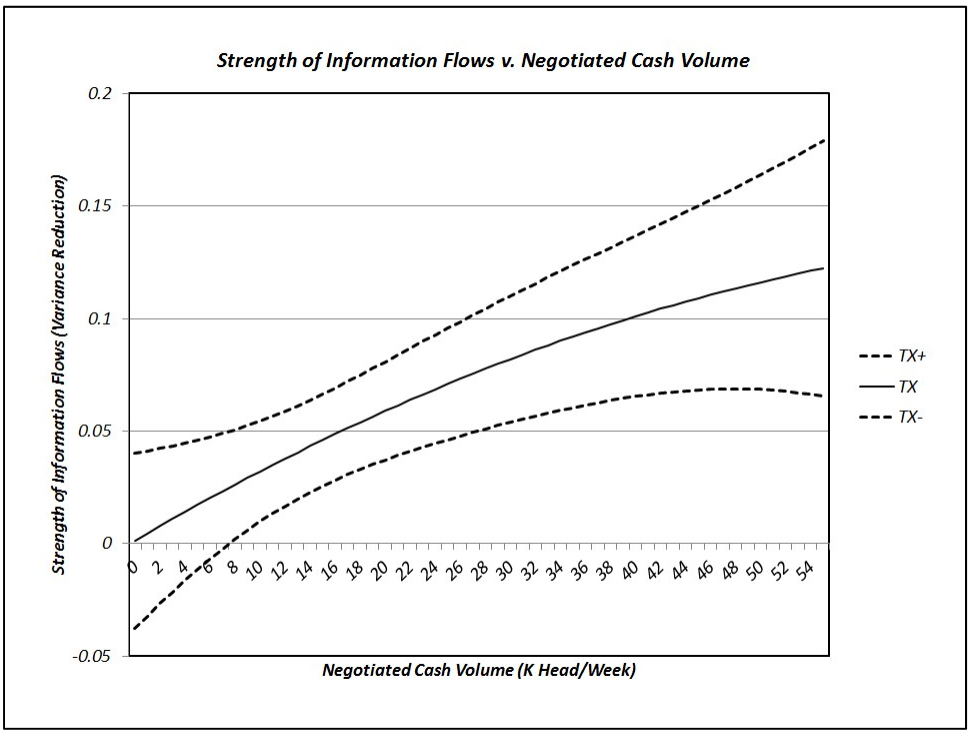

Figure 20: Relationship Between Negotiated Cash Volume and the Strength of Information Flows from Texas-OK-NM to Other Regional Fed Cattle Markets.

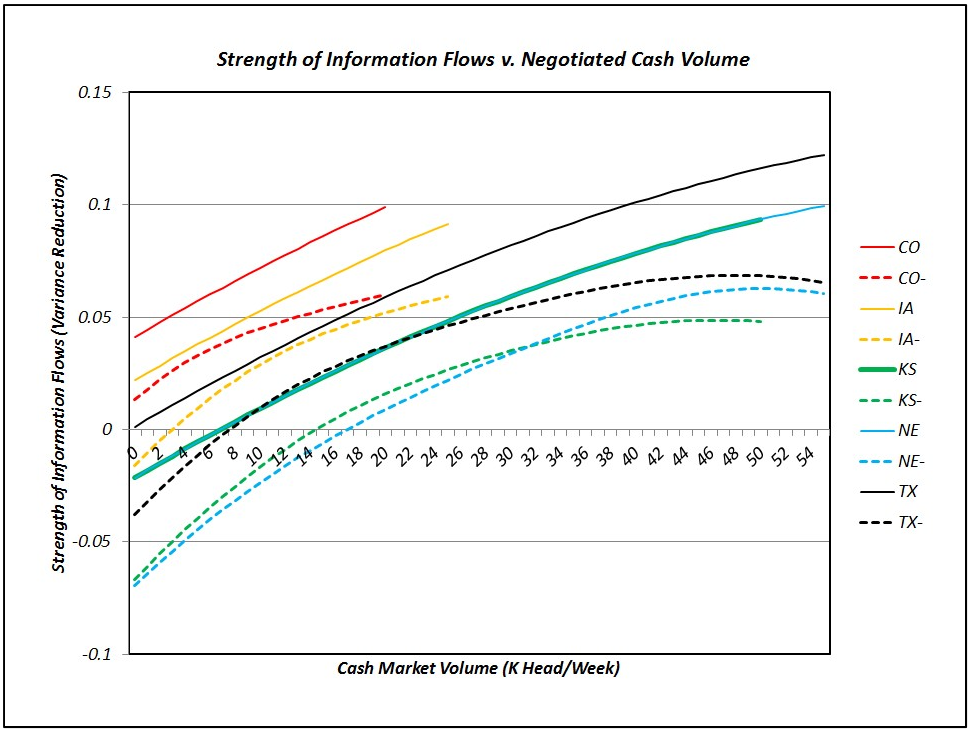

Figure 21: Simple Regression Relationships Between Negotiated Cash Volume and the Strength of Information Flows from Each Listed Regional Fed Cattle Market to Other Regional Fed Cattle Markets.

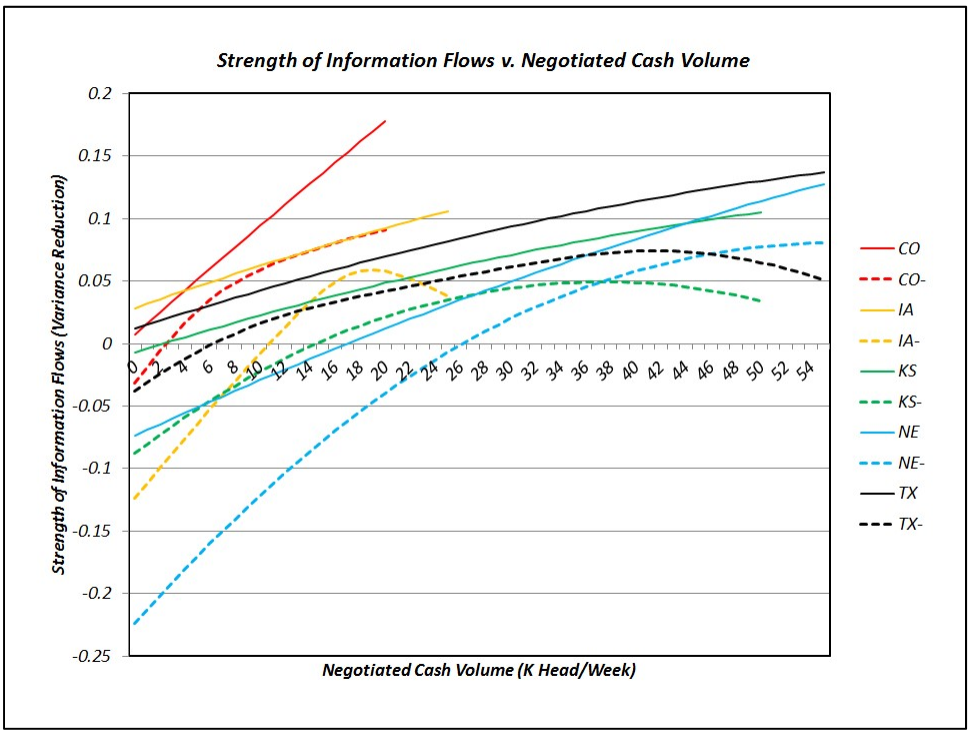

Figure 22: Flexible Regression Relationship Between Negotiated Cash Volume and the Strength of Information Flows from Each Listed Regional Fed Cattle Market Other Regional Fed Cattle Markets.

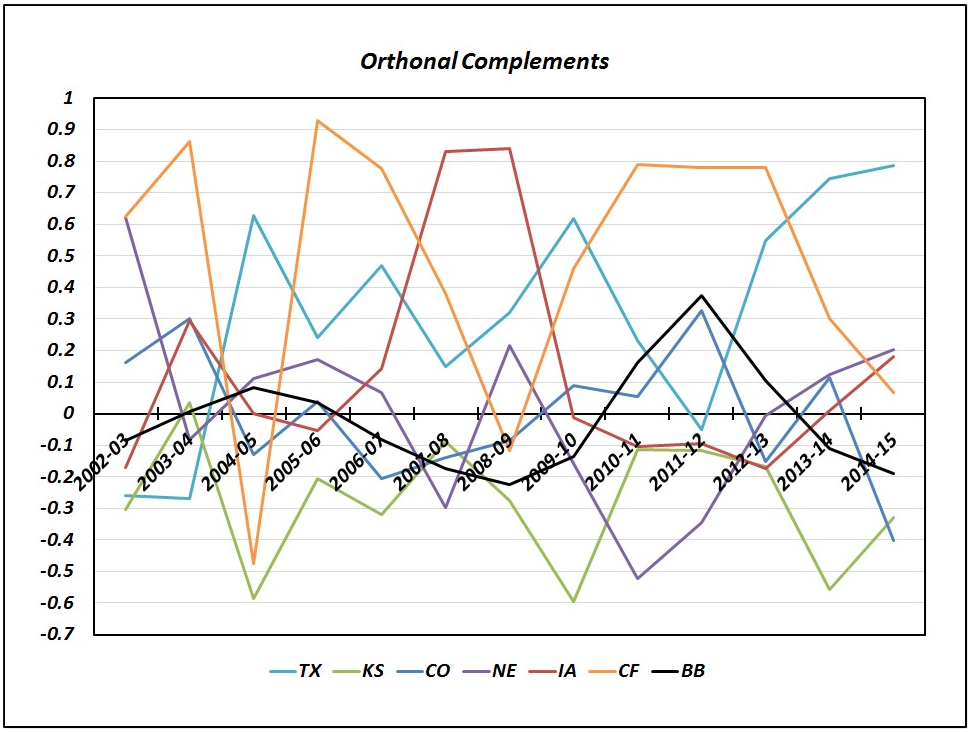

Figure 23: Orthogonal Complements Measuring the Weights Associated with each Regional Cash Market in the Common Trend Across Time.

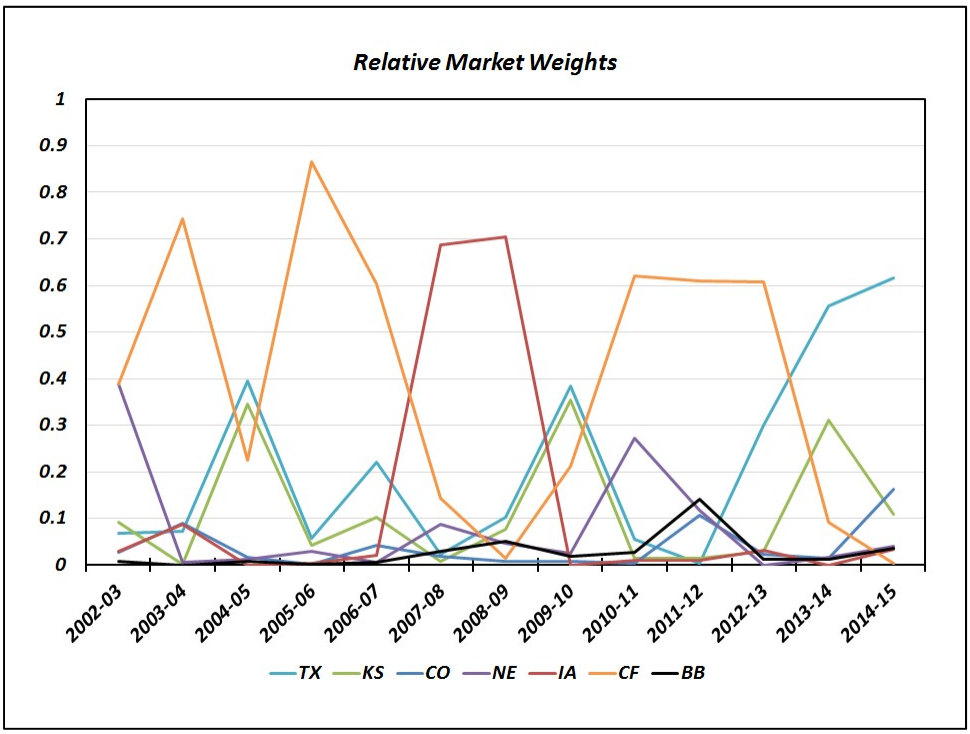

Figure 24: Relative Market Weights in Contribution to Price Discovery Across Time.

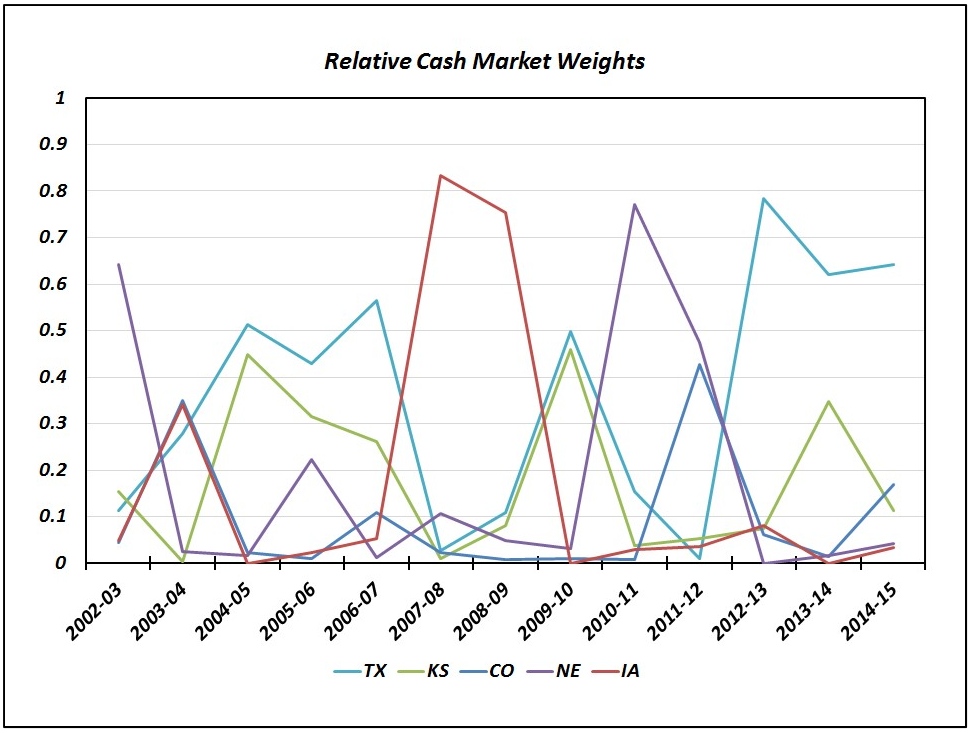

Figure 25: Relative Cash Market Weights Across Time.

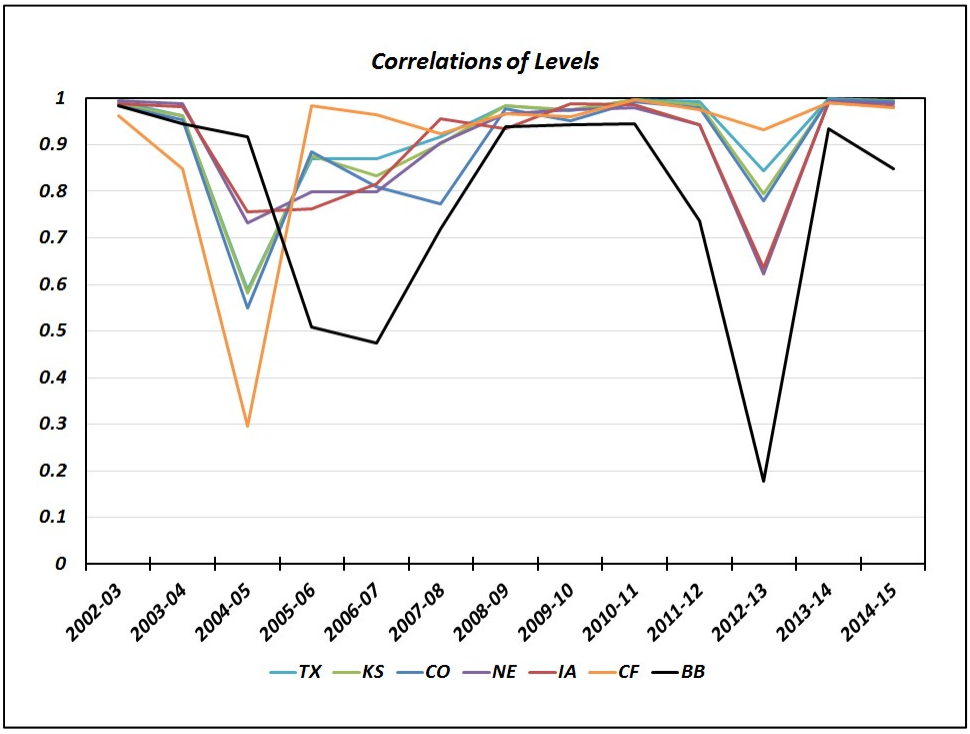

Figure 26: Correlations of the Common Trend and Regional Fed Cattle Market Prices – in Levels – Across Time.

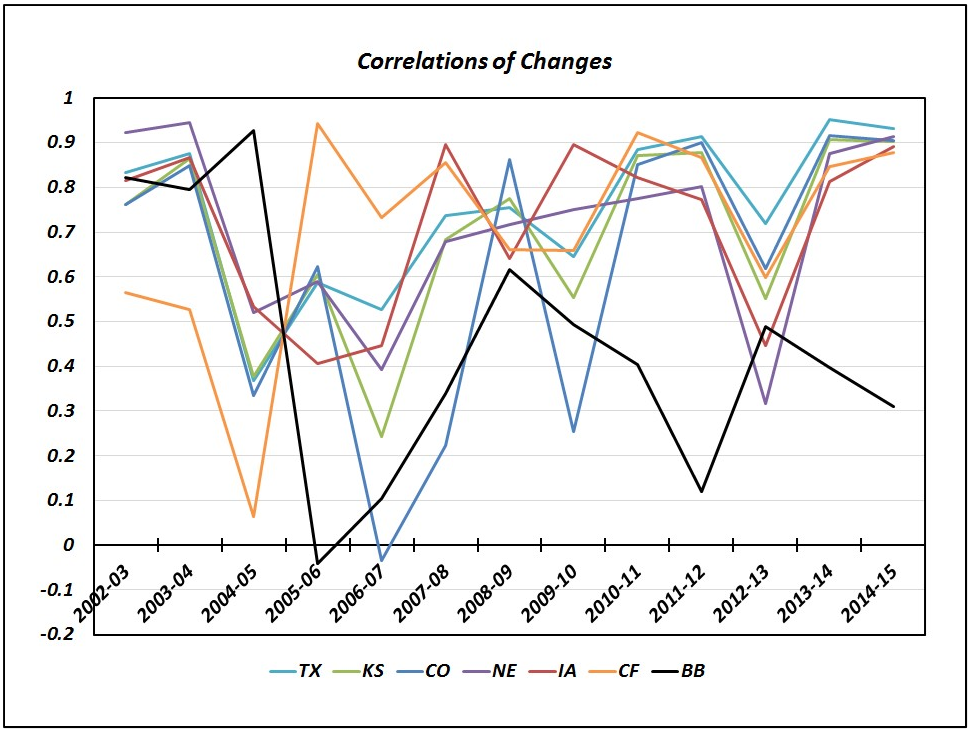

Figure 27: Correlations of the Common Trend and Regional Fed Cattle Market Prices – in Changes – Across Time.