Spatial market integration ensures price discovery, market efficiency and market competition. Price integration in fed cattle markets is a significant subject of research due to perishable nature of fed cattle, geographical distance between production and consumptions areas, and considerable transportation cost. This study examines United States fed cattle market integration using weekly price series of live steer and heifer for five major fed cattle markets in the era of Livestock Mandatory Price Reporting Act. Results indicate that all markets are cointegrated with sharing a common stochastic trend suggesting the Law of One Price. Causal relationship was found among most of the regional markets in case of steer prices, while the relationship was absent among most of the markets for heifer prices.

Keywords: Spatial market integration; Price co-integration; Price relationship

1 Introduction

Market integration implies co-movements of prices and transmission of price signals and information across spatially separated markets. Price series are said to be cointegrated when a long-run linear relation exists among these series (Engle and Granger 1987). The presence of cointegration between two price series indicates long-run spatial price equilibrium and market integration. On the contrary, if prices diverge from one another and this integration is absent, then there exists a state of market segmentation. The study of the fed cattle market is important due to the bulky and perishable nature of fed cattle and the geographical distance between sites of production and consumption for which market segmentation can exist (Pendell and Schroeder 2006). If markets are segmented, price signals and information will not be transmitted across markets resulting in deficit cattle volumes in some regions and surplus cattle volumes in other regions. Market integration ensures an equilibrium among food-deficit and food-surplus regions (Delgado 1986). Spatial market integration defines geographic markets, promotes market competitions, ensures price discovery and assesses market performance. An indirect approach to analyze market efficiency is to measure market integration (Hopcraft 1987). Moreover, knowledge of degree of market integration is a vital instrument for policy makers to formulate policies regarding market liberalization and price stabilization.

Since about 1946, participants in the fed cattle industry have relied on market news reports generated by Agriculture Marketing Service (AMS) of United States Department of Agriculture (USDA), for price information (Perry et al. 2005). These reports were generated based on a voluntary price reporting system by producers, packers, feedlot operators and other participants in the industry. In late 1990s, the voluntary price reporting system was criticized for not being representative since cattle feeders rapidly adopted alternative methods of selling cattle such as contracts and formula pricing (Grunewald et al., 2004; Pendell and Schroeder 2006). To address this issue, the US Congress passed Livestock Mandatory Reporting Act (LMRA) of 1999, which came into effect in April 2001. The act required plants slaughtering 125,000 head of cattle or more annually to report daily prices, volumes, purchase contracts and price agreements to AMS twice daily to facilitate transparent price discovery and provide timely market information to all participants (Azzam 2003; Perry et.al 2005). The LMRA act was renewed and amended in 2005, 2010 and 2015 (Mathews et al. 2015; USDA 2018, retrieved from https://www.ams.usda.gov/rules-regulations/mmr/lmr) and is now expected to provide complete clarity of price and transaction information to participants in the fed cattle industry, thereby increasing market integration among spatial markets.
The objective of this study was to investigate spatial market integration and causal relationship among five major U.S. regional fed cattle markets namely Colorado Direct, Iowa-Southern Minnesota Direct, Western Kansas Direct, Nebraska Direct and Texas-Oklahoma Direct in the LMRA era. This study has an important implication to understand the most recent picture of fed cattle market integration since fed cattle market has experienced significant changes over the past decades due to LMRA. The performance of regional fed cattle markets in terms of price co-integration should be better understood by this study.

The weighted-average weekly prices for live steer and heifer at five regional markets from March 2001 to March 2015 were analyzed to examine market integration. Engle-Granger (1987) and Gregory-Hansen’s (1996) bivariate cointegration tests and Johansen (1988) multivariate cointegration test were used to investigate how spatially distant fed cattle markets are linked together via prices. Finally, Granger causality test was performed to determine the extent to which lagged prices for one market influence prices in another market.

2 Market Integration – A methodological review

This section reviews previous studies related to market integration and price relationships within the livestock industry in United States. Several studies have been conducted considering cointegration and dynamics of spatial price behavior in fed cattle market in U.S., for example Bailey and Brorsen (1985), Koontz et al. (1990), Schroder and Goodwin (1990), Goodwin and Schroder (1991), Fausti and Diersen (2004), Pendell and Schroeder (2006), Franken et al. (2011), Ward et al. (2014) and Mathews et al. (2015).

Bailey and Brorsen (1985) investigated the dynamics of regional fed cattle prices using multivariate autoregressive analysis and the causality test in the Texas Panhandle, Omaha, Nebraska, Colorado-Kansas, and Utah-Eastern Nevada-Southern Idaho markets from 1978 to 1983. Price adjustments to new information were not instantaneous and so it took about one week. Texas Panhandle market led cattle prices in the other three regional markets.

Koontz et al. (1990) examined dominant-satellite relationships using Granger causality test. Weekly fed cattle prices in four direct and four terminal markets were studied from January 1973 to December 1984 and it was shown that direct markets dominated.

Schroder and Goodwin (1990) used a multivariate vector autoregressive (VAR) model to identify regional fed cattle prices dynamics. Eleven direct and terminal trade cattle markets were examined using weekly average steer price data from 1976 through 1987. Cattle markets with larger volumes took less time than those with smaller volumes to fully react to price changes at the other major cattle markets.

Goodwin and Schroeder (1991) investigated cointegration and spatial price linkages for 11 U.S. regional slaughter cattle markets. Weekly price data for slaughter steers were used from 1980 to 1987. Cointegration among weekly price series was increased over time and prices were also influenced by distances between the cattle markets.

Fausti and Diersen (2004) tested the relationship between voluntary prices reporting in Nebraska Direct and mandatory price reporting in South Dakota from 1999 to 2001. The voluntary price reporting system was as efficient as the mandatory price reporting system.

Pendell and Schroeder (2006) examined the impact of increased information in the public domain due to Mandatory Price Reporting (MPR) on the price integration in 5 regional fed cattle markets namely Colorado Direct, Iowa-Minnesota Direct, Western Kansas Direct, Nebraska Direct and Texas Oklahoma Direct using data from 1992 through 2006. Their results suggested fed cattle markets were integrated before MPR but following the introduction of MPR the regional markets became more integrated. MPR increased market information by providing all types of selling methods including contract and formula price agreement and supply and demand situation which enhanced spatial market efficiency.

Franken et al. (2011) examined the impact of mandatory price reporting on hog market integration in US. The findings indicated that hog markets were cointegrated before and after LMRA but not fully integrated in either period.

Ward et al. (2014) investigated the relationships among Alternative Marketing Arrangement (AMA) prices for fed cattle and hog after the implementation of MPR. The relationship between negotiated cash prices and AMA prices was found relatively strong. Negotiated cash prices were above AMA prices in upward moving markets while it was below AMA prices in downward moving markets both for fed cattle and hogs.

Mathews et al. (2015) analyzed livestock market efficiency, price behavior and price discovery before and after implementation of LMRA and found that the increased flow of market information with LMRA better informs the broader market. Market efficiency and price discovery were also found to be better in the LMRA period.

The previous studies on fed cattle market integration
are more than 10 years old. However, fed cattle market has changed significantly during 2000s due to LMRA, for which a current assessment of spatial fed cattle market integration is inevitable and this study fills the gap by analyzing the most recent picture in the era of LMRA.

3 Methodology

Both bivariate and multivariate time-series frameworks were used to measure fed cattle market integration. The first step in testing for cointegration in these framework is to test the presence of a unit root in each of the price series using Dicky-Fuller (DF) test (Dickey and Fuller 1979) Augmented Dickey Fuller test (Dickey and Fuller 1981), Philips-Perron test (Perron 1989) and few other tests. The null hypothesis in ADF test is that there is a unit root in the price series. The series is nonstationary if the null hypothesis is not rejected. If the series becomes stationary after first differencing then the next step is to test cointegration among price series. ADF test tends to have false conclusion under structural break in the time series (Perron 1989). Hence, Philips-Perron unit root test was also conducted to overcome the limitations of ADF test.

The Engle-Granger (1987) bivariate methodology was used to test any long run equilibrium relationship between the two price series relationship in the following form:

\[ y_t = \alpha + \beta x_t + \epsilon_t \]  (1)

Where, \( y_t \) and \( x_t \) represent the two price series, \( \alpha, \beta, \epsilon_t \) are intercept, slope and error term respectively.

In order to test the cointegration between \( y_t \) and \( x_t \), the stationarity test for the estimated residuals \( \epsilon_t \) form equation (1) was done by Augmented Dickey Fuller test. If there is a unit root in the residual series, \( y_t \) and \( x_t \) are not cointegrated. The Engle-Granger bivariate test is easy to implement but was criticized since the result might depend on price series which is used in the left side. The test was also criticized for testing multiple cointegration relationship and large bias in small sample.

Gregory-Hansen (1996) cointegration test was also used to allow any structural changes in the price series due to major policy change or other kinds of shocks. Cointegrating relationships can be changed by the structural break in the price series. The estimation procedure of Gregory-Hansen is similar to Engle-Granger cointegration test procedure.

Johansen (1988) cointegration test is a multivariate approach for testing cointegration which begins with a Vector Autoregressive (VAR) model:

\[ P_t = A_0 + A_1 P(t-1) + ... + A_k P(t-k) + \epsilon_t \]

Where, \( P_t \) is a (nx1) vector of the price series; \( A_i \)'s are matrices of parameters; \( k \) is lag length; \( \epsilon \) is vector of independently and identically distributed residuals. The next step is to reform the VAR model into a Vector Error Correction (VECM) form:

\[ \Delta P_t = \tau_0 + \tau_1 \Delta P(t-1) + ... + \tau_{k-1} \Delta P(t-(k-1)) + \pi P(t-k) + \epsilon_t \]

Where, \( \Delta P_t \) is a (nx1) vector of the price series in first differences; \( \tau_0 = A_0; \tau_i \)'s and \( \pi \) are (nxn) matrices of parameters. The number of independent co-integrating vectors is determined by the rank of the matrix \( \pi \) of the VECM. Cointegration exists if the matrix \( \pi \) has a rank, \( r>0 \). If cointegration occurs, there will be \( n-r \) stochastic trend with prices in \( n \) markets (Stock and Watson 1988). All prices are pairwise cointegrated, if there are \( n-1 \) cointegrating vectors. This implies all of the five regional cattle market series have the same stochastic trend when there are four cointegrating vectors. The price series are not fully integrated if there are more than one common stochastic trends.

The Johansen procedure is based on maximum likelihood estimation of the VECM. To determine the number of cointegrating vectors in the system, the trace and the maximum eigenvalue test statistics are used. The null hypothesis for both tests is that there are at most \( r \) cointegrating vectors in the system. In the case of trace test, the alternative hypothesis is that there exist more than \( r \) cointegrating vectors. The alternative hypothesis for the maximum eigenvalue test is that the number of cointegration vectors is equal to \( r+1 \).

Granger causality test was performed to identify the predictive power of one price series to explain another price series. The method employs an error correction mechanism to determine the extent to which current and past price changes in one market explain price changes in another. The error correction model (ECM) (Engle and Granger 1987) exists if price series are co-integrated. The ECM conveys short-run and long-run information between markets and also determine the relevant direction of the flow of price information.

3.1 Data

Weekly price series for five regional fed cattle markets namely Colorado Direct, Iowa-Southern Minnesota Direct, Western Kansas Direct, Nebraska Direct and Texas-Oklahoma Direct were assembled from AMS reports for the period May 2001 to March 2015. Availability of data and
representativeness of the cattle industry are the reasons for selecting these markets. These regional markets represent more than 80% of total U.S. fed cattle market trade (Pendell and Schroeder 2006). Moreover, after the implementation of LMRA, fed cattle price data have been continuously collected and reported for these markets only. Price information was available for different qualities of both live and dressed steers and heifers. However, weighted-average price of live steer and live heifer for each market has been chosen for analysis due to large volume of trade in these cattle. The summary statistics of five regional fed cattle markets are illustrated in Table 1.

Table 1 shows that mean, minimum and maximum cattle prices in different regional fed cattle markets were almost same for the time period, which might be a primary evidence of market integration.

Figure 1 (a and b) illustrates that weekly steer and heifer prices in five regional markets exhibit fairly similar patterns in the era of LMRA. Fed cattle prices were steadily increased during this period.

Ethical approval: The conducted research is not related to either human or animal use.

### Table 1: Summary Statistics of Weekly Steer and Heifer Prices, May 2001-March 2015

<table>
<thead>
<tr>
<th>Regional Market</th>
<th>Weekly live steer price</th>
<th>Weekly live heifer price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa-Minnesota</td>
<td>718</td>
<td>98.11</td>
</tr>
<tr>
<td>Colorado</td>
<td>718</td>
<td>98.66</td>
</tr>
<tr>
<td>Nebraska</td>
<td>718</td>
<td>98.45</td>
</tr>
<tr>
<td>Kansas</td>
<td>718</td>
<td>98.45</td>
</tr>
<tr>
<td>Texas-Oklahoma</td>
<td>718</td>
<td>98.53</td>
</tr>
</tbody>
</table>

Figure 1a: Weekly Live Steer Prices ($/CWT), May 2001-March 2015

Figure 1b: Weekly Live Heifer Prices ($/CWT), May 2001-March 2015
4 Results

This section reports the results of the cointegration tests and Granger causality test mentioned in the methodology section.

4.1 Stationarity Test

The results (Table 2) from both ADF and PP tests indicate weekly all live steer and heifer price series were not stationary in levels.

To check whether the series was integrated of order one \([I(1)]\), first difference of each price series was taken and data series were tested for non-stationarity again with ADF and PP tests. Now, price series were found to be stationary at 1% significance level in case of both tests. Hence, the price series were declared to be integrated of order one \([I(1)]\).

4.2 Cointegration test

Given that price series were all integrated of order one \([I(1)]\), Engle-Granger and Gregory-Hansen Bivariate test and Johansen's Multivariate Cointegration tests were applied to the price series in levels to examine any long-run relationship among price series. Gregory Hansen test was applied allowing change in regime and trend. Lag length was selected according to the minimum Akaike information criterion. Table 3 illustrates bivariate cointegration test results for fed cattle markets.

The null hypothesis of no cointegration was rejected for both bivariate tests across all fed cattle markets including steer and heifer. This implies there is an equilibrium relationship between fed cattle markets. Specifically, all markets were pairwise integrated all over the period of MPR.

In order to further investigate, Johansen's multivariate test for cointegration was conducted with a linear trend in cointegration equation. If there are \(n-1\) cointegrating vectors then all the price series share a common stochastic trend suggesting that the Law of One Price (LOP) holds for the commodity market (Sharma 2003). The Johansen cointegration results (Table 4) based on both Trace Statistic and Maximum Eigen Value Statistic indicate the presence of four cointegrating vectors in both steer and heifer price series. In other words, price series in all five regional fed cattle markets observed the same stochastic trend.

<table>
<thead>
<tr>
<th>Regional Market</th>
<th>Weekly Steer Price</th>
<th>Weekly Heifer Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level (with trend)</td>
<td>First difference (with trend)</td>
</tr>
<tr>
<td></td>
<td>ADF</td>
<td>PP</td>
</tr>
<tr>
<td>Nebraska</td>
<td>-1.872</td>
<td>-2.316</td>
</tr>
<tr>
<td>Texas-Oklahoma</td>
<td>-1.904</td>
<td>-2.258</td>
</tr>
</tbody>
</table>

Note: (*) denotes 1% significance level; critical value at the 1% significance level is -3.960 for a model with trend (MacKinnon, 1996)

Table 2: Augmented Dickey Fuller and Phillips-Perron Unit Root Test for Live Steer and Heifer Price Series

<table>
<thead>
<tr>
<th>Dependent Market / Independent Market</th>
<th>Weekly Steer Price</th>
<th>Weekly Heifer Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa-Minnesota/ Colorado</td>
<td>-7.858*</td>
<td>-6.66*</td>
</tr>
<tr>
<td>Iowa-Minnesota/ Nebraska</td>
<td>-7.678*</td>
<td>-7.19*</td>
</tr>
<tr>
<td>Iowa-Minnesota/ Kansas</td>
<td>-6.741*</td>
<td>-6.98*</td>
</tr>
<tr>
<td>Iowa-Minnesota/ Texas-Oklahoma</td>
<td>-6.832*</td>
<td>-7.03*</td>
</tr>
<tr>
<td>Colorado/ Nebraska</td>
<td>-9.743*</td>
<td>-9.01*</td>
</tr>
<tr>
<td>Colorado/Texas-Oklahoma</td>
<td>-8.503*</td>
<td>-8.07*</td>
</tr>
<tr>
<td>Nebraska/Kansas</td>
<td>-7.084*</td>
<td>-8.35*</td>
</tr>
<tr>
<td>Nebraska/Texas-Oklahoma</td>
<td>-7.068*</td>
<td>-8.15*</td>
</tr>
<tr>
<td>Kansas/Texas-Oklahoma</td>
<td>-10.910*</td>
<td>-11.92*</td>
</tr>
<tr>
<td>1% critical value</td>
<td>-3.960</td>
<td>-5.47</td>
</tr>
</tbody>
</table>

Note: (*) denotes 1% significance level
causality test determines the influence of lagged prices in one market over prices in another market. The null hypothesis of the test is that one market does not influence prices in another market which can be rejected if the p value is less than 5%.

Table 5 represents the result of Granger causality tests in the period of MPR. In case of steer price, all null hypothesis of Granger causality were rejected at significant level except 4 null hypothesis. In other words, prices in one market influence another market. All regional fed cattle markets have causal relationship except Iowa-Minnesota. Iowa-Minnesota steer price does not Granger there was a spatial equilibrium price relationship among all five regional fed cattle markets which implies that price series did not significantly diverge to one another. These results support the findings of Pendell and Schroeder (2006).

4.3 Granger Causality Test

Granger causality test is a statistical hypothesis test to determine whether one time series is useful to predict another time series. In case of fed cattle market, Granger causality test determines the influence of lagged prices in one market over prices in another market. The null hypothesis of the test is that one market does not influence prices in another market which can be rejected if the p value is less than 5%.

Table 5 represents the result of Granger causality tests in the period of MPR. In case of steer price, all null hypothesis of Granger causality were rejected at significant level except 4 null hypothesis. In other words, prices in one market influence another market. All regional fed cattle markets have causal relationship except Iowa-Minnesota. Iowa-Minnesota steer price does not Granger...
cause to other market prices but the market price of Iowa-Minnesota is influenced by other market price. The reason behind the Granger cause between these markets might be that they are located at same geographic area and have also similarities in cattle type. Price transmission between these markets happens quickly due to close distance, improved marketing and communication structure and available price information. However, all null hypothesis of Granger causality cannot be rejected in case of heifer price series except 4 null hypotheses. Only Texas-Oklahoma market has influence on other regional markets for heifer prices that means Texas-Oklahoma market is the dominant market. The absence of causal relationship might be due to the small market share of heifers compared to steers.

5 Conclusions

Market integration captures the degree of co-movement of prices across spatially separated markets. Spatial market integration in cattle market has important implication in increasing market efficiency, promoting competition and defining geographic markets. Before 2001, fed cattle market participants used to rely on voluntary price reporting generated by Agricultural Marketing Service (AMS) of USDA. Since voluntary price reporting was not representative to all transactions, the LMRA was implemented in 2001 to increase the flow of transaction information and facilitate the price discovery (Mathews 2015). Previous literatures suggest the mixed impact of LMRA. Fausti and Diersen (2004) found the voluntary price reporting system was as efficient as the mandatory price reporting system, while Pendell and Schroeder (2006) suggested that following the introduction of MPR the regional fed cattle markets became more integrated. However, the previous studies are too old to understand the recent picture of fed cattle market which has been significantly changed due to LMRA. This study contributes a better understanding of the recent picture of regional fed cattle market integration and price transmission from one location to another.

Both bivariate and multivariate cointegration tests were applied to examine the spatial price relationship among five major fed cattle market namely Colorado Direct, Iowa-Minnesota Direct, Western Kansas Direct, Nebraska Direct and Texas Oklahoma Direct using weekly price series of live steer and heifer from May 2001 through March 2015. All of the weekly price series were found nonstationary in levels and stationary in first differences by both ADF and PP tests. The Engle-Granger and Gregory-Hansen Bivariate test indicated an equilibrium relationship among all five regional fed cattle market i.e. all markets were pairwise integrated. This fact was also supported by Johansen multivariate cointegration test. This implies that all five markets were cointegrated over the period of MPR, having a common stochastic trend. Causal relationship was found among most of the regional markets in case of steer prices, while it was absent among most of the markets for heifer prices. These findings perhaps reflect the influence of Mandatory Price Reporting which enhance price discovery and more reliable market information on all kinds of transactions.

Overall, the findings of this study are useful to understand the degree of market integration and the price relationship among fed cattle markets. Regional fed cattle markets in United States are well integrated reflecting a satisfactory level of price and an efficient marketing system. Policy makers can uphold MPR since it ensures increased and transparent market information that leads to spatial market integration. Further research may investigate the price dynamics from one market to another both in the short-run and the long-run.

Conflict of interest: Authors state no conflict of interest.

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