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**Examining Dynamically Changing Cattle Market Linkages with Inventory as Controlled
Transitions**

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Abstract:

This article reports tests of price cointegration of cattle markets in the U.S. and proposes a simple procedure for incorporating a flexible transition function into the ECON smooth transition autoregressive (ECON – STAR) model to evaluate market dynamics over time. This model allows evaluating varying market integration as an exogenous economic indicator changes throughout a specified time. Cattle are perishable, bulky and costly to transport. These characteristics make cattle markets easily segmented across regions. The empirical results show that these markets have been highly cointegrated when there exists excess supply. Following a sudden decrease in cattle inventory, the market pattern has become very regionally segmented.

Introduction:

Under the assumption of a competitive market structure with a homogenous commodity and no trade barriers, price differences between any two regions that trade with each other will just equal transfer costs. This principle is usually referred to as the Law of One Price (LOP) in a spatial dimension. Geographical price relationships can be analyzed by using spatial price equilibrium models (Tomek and Kaiser). A set of prices can be obtained from the optimum that is determined by the model, given the supply and demand conditions within each region. If regional prices are adjusted for transfer costs, the law of one price should hold in competitive markets when there are no trade barriers. Markets are considered inefficient if profitable arbitrage opportunities exist. The law of one price has been the basis for numerous tests of market efficiency and market integration (e.g., Ravallion 1986; Barrett and Li 2002; Negassa and Myers 2007).

Cointegration tests provide a suitable framework in which to consider long-run price relationships among several regional cattle markets. The empirical applications by Goodwin and Schroeder (1991) suggest that cointegration of regional cattle prices is limited by conducting seven cointegration tests proposed by Engle and Granger (1987), indicating the existence of segmented markets over which arbitrage opportunities are necessarily precluded by barriers such as high transactions costs. They also found that the degree of cointegration increased over time in the markets analyzed by constructing a model including factors that influence the degree of cointegration among regional cattle markets. A rational expectation model applying GMM has

also been used to test spatial integration in regional slaughter steer markets (Goodwin and Schroeder, 1990). Their results indicate limited integration and suggest a shift in spatial price linkages between regional markets between 1980 and 1987. More recently, nonlinearities induced by unobservable transactions costs are modeled by estimating Time-Varying Smooth Transition Autoregressions (TV-STARs). Results indicate that nonlinearity and structural change are important features of these markets; price parity relationships implied by economic theory are generally supported by the estimated models (Goodwin, Holt and Prestemon, 2010). Hood and Dorfman (2014) constructed an ECON-STAR model to capture the relationship between housing starts and south-wide pine sawtimber stumpage prices. An economic indicator is included in the model to explain price cointegration.

In addition, numerous studies have tested price cointegration and dynamics of spatial price behavior in live cattle markets. In the research of Schroeder (1997), distances between cattle markets, size and ownership of packing plants, and procurement methods of cattle all affected the degree of cointegration. Pendell and Schroeder (2006) found that the studied five regional cattle markets have been, and remain, highly cointegrated after implementation of mandatory price reporting (MPR).

In this paper, we are interested in whether excess cattle inventories encourage efficient trading. Thus, as the volume of cattle inventories changes, we are curious about the changes in the market linkages of the numerous, regional micro-markets. To develop this topic, we are going to test whether excess inventory has an impact on the cointegration of cattle prices in U.S. cattle markets by applying the work of Hood and Dorfman (2014), the generalized smooth transition autoregressive (STAR) model with an outside economic indicator. The advantage of this model is that it allows for the possibility of gradual adjustments among price linkages and structural change and allows us to see how market dynamics change over time in response to variation in the embedded exogenous economic indicator.

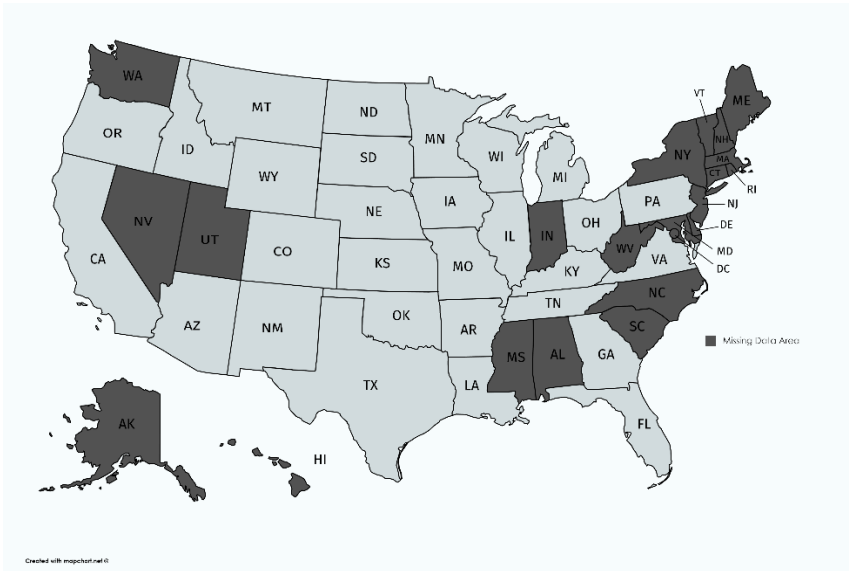
We have three key contributions in this paper. First, the transition function in the ECON-STAR model is modified to bring more flexibility. we leverage the cumulative distribution function (cdf) of the standard normal distribution in the model, which eliminates the concern of the 'minimum value' problem in the previous literature. In the original ECON-STAR model, the transition variable will reach zero at least once when the exogenous indicator's level reaches its

minimum value, thus making a pair of regions unlink at least once even if they never did in fact. The nice features of the cdf of the standard normal distributions such as positivity, monotonicity, and continuity give the model higher flexibility and a better description of how markets link and unlink over time. Second, while cattle industry and cattle market have undergone considerable structural change, there is a limited number of published and updated works testing spatial cattle price cointegration. Third, by using adjusted inventory as the transition variable, the empirical results show how important excess regional supply in the market is for maintaining market integration. The analysis provides economists and policymakers with information regarding the true driving force of cattle market linkages.

Data Description

The annual prices price series for more than 500 pounds cattle and levels of inventories (measured in heads) for cattle including calves were assembled for 29 states (Arizona, Arkansas, California, Colorado, Florida, Georgia, Idaho, Illinois, Iowa, Kansas, Kentucky, Louisiana, Michigan, Missouri, Nebraska, New Mexico, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, South Dakota, Tennessee, Texas, Virginia, Wisconsin, Wyoming, Minnesota, Montana) over the period from 1950 through 2010, yielding a total of 61 observations per state. Figure 1 shows the data coverage of our study where dark areas indicate that data are not available for that state.

Figure 1. Data Coverage Map



The number of slaughtered cattle was chosen as the indicator for cattle demand for the reason that slaughtered cattle constitute over 90 percent of the total disappearance of cattle apart from deaths and exports. The data were collected from the National Agricultural Statistics Service (NASS) of United States Department of Agriculture (USDA).

Figure 2. Annual Cattle Prices \$/cwt vs Cattle Inventories, 1950 – 2010.

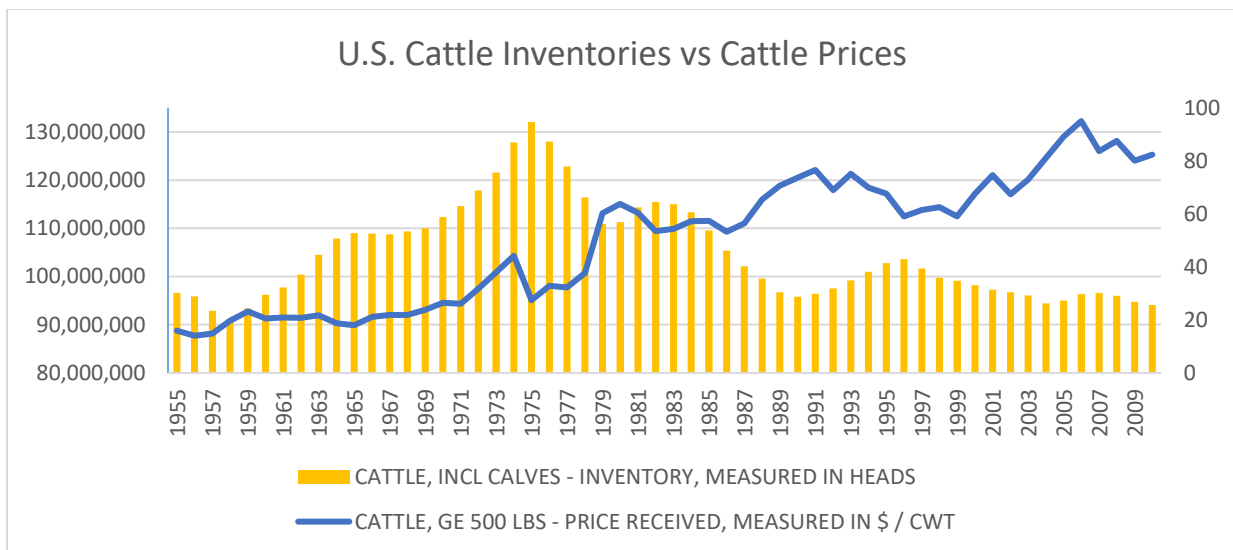
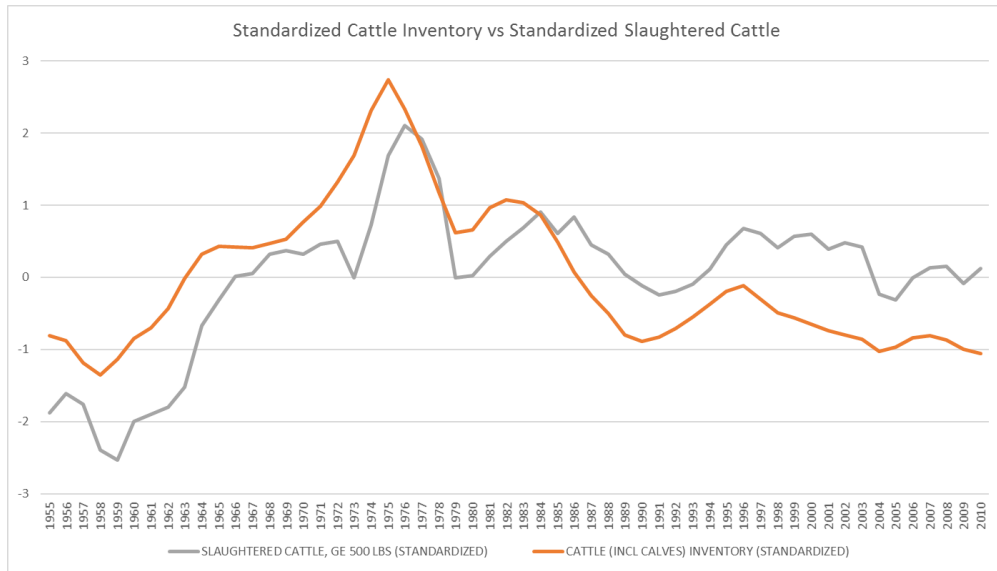


Figure 2 illustrates the annual prices of cattle that is over 500 lbs in \$/cwt and annual level of inventories of cattle (including calves) in heads from 1955 to 2010, showing the overall long-

term history of the U.S. cattle market. As cattle prices climb over time, the level of cattle inventories expanded steadily since the 1950s reached its peak in 1975, and underwent a noticeable decline afterwards. We want to capitalize on the relationship between the level of cattle inventories, which is used as the economic indicator to study market linkages in this paper, and prices of cattle.

Figure 3. Standardized Annual Cattle Inventories vs Standardized Cattle Disappearance, 1950 – 2010.



We standardized the series of cattle inventory and cattle disappearance to make them comparable. Figure 3 shows the standardized annual number of slaughtered cattle and the standardized annual level of inventories of cattle (including calves). As an indicator of the demand for live cattle, the number of slaughtered cattle exhibit nearly the same trend as cattle inventories which can be considered as the supply of live cattle.

Econometric Model

Let $y_t = \ln\left(\frac{p_{it}}{p_{jt}}\right)$ for some market i and j . We may then specify a linear p^{th} -order autoregressive model for the price pair as

$$(1) \quad \Delta y_t = \phi_0 + \phi' x_t + \theta y_{t-1} + \varepsilon_t$$

where $\boldsymbol{\phi} = (\phi_1, \dots, \phi_{p-1})$, $x_t = (\Delta y_{t-1}, \dots, \Delta y_{t-p+1})$, ε_t is a mean-zero iid error term with finite variance. Lag length p may be chosen by using a model selection criterion such as Akaike's Information Criterion (AIC).

In the basic STAR modeling framework used to investigate the LOP, the linear autoregression in the previous equation is typically modified as follows

$$(2) \quad \Delta y_t = \tilde{\phi}'_1 \tilde{x}_t [1 - G(s_t; \gamma, c)] + \tilde{\phi}'_2 \tilde{x}_t G(s_t; \gamma, c) + \varepsilon_t$$

where $\tilde{x}_t = (1, x_t, y_{t-1})$, $\tilde{\phi}'_1 = (0, \phi_1, 0)$, $\tilde{\phi}'_2 = (\phi_{2,0}, \phi_1, \theta_2)$, and where $\theta_2 < 0$ is required. As well c may either be scalar- or vector-valued. $G(s_t; \gamma, c)$ is called the transition function and varies in a potentially smooth manner between zero and one according to a "transition" variable s_t and whose properties are determined by the values of the speed-of-adjustment parameter $\gamma > 0$ and the location parameter(s), c . The transition variable s_t maybe a function of nearly any observed variable, but in practice it is typically taken to be some function of the lagged dependent variable, y_t . For example, Killian and Taylor (2003), in their investigation of the behavior of real exchange rates based on fundamentals of purchasing power parity (PPP), suggest using something like

$$(3) \quad s_t = \left(\frac{1}{D_{max}}\right) \sum_{d=1}^{D_{max}} y_{t-d} ,$$

where D_{max} is a pre-specified lag limit. The specification in equation (3) is also consistent with the notion that profit opportunities occur when large deviations in relative prices occur from some moving average.

A number of candidates have been selected for the transition function $G(\bullet)$ in equation (2). Even so, one that has been used extensively in price parity analysis is the exponential or ESTAR model. (see, e.g., Fan and Wei 2006; Kilian and Taylor 2003; Paya and Peel 2004; Taylor, Peel, and Sarno 2001). The ESTAR model specified the transition function as

$$(4) \quad G(s_t; \gamma, c) = 1 - \exp[-\gamma(s_t - c)^2],$$

where c is the location parameter and γ is the speed-of-adjustment parameter, and where $\gamma > 0$ is required. Another popular version is the logistic STAR (LSTAR) model. The transition function of the LSTAR model can be specified as

$$(5) G(s_t; \gamma, c) = \{1 + \exp[-\gamma(s_t - c)^2]\}^{-1},$$

where $\gamma > 0$ is required. An alternative to the ESTAR model and one that is also used to study the LOP and PPP is the quadratic STAR (QSTAR). The QSTAR model contain a second-order logistic function and was initially proposed by Jansen and Teräsvirta (1996). The transition function of the QSTAR model contains location parameters, $c = (c_1, c_2)$, and is given by

$$(6) G(s_t; \gamma, c) = \{1 + \exp[-\gamma(s_t - c_1)(s_2 - c_2)]\}^{-1},$$

where both $\gamma > 0$ and $c_1 \leq c_2$ is required.

A most recent version of transition function is the ECON-STAR model proposed by Hood and Dorfman (2015). The transition function is given by

$$(7) G(s_t; \gamma, c) = 1 - \exp\left\{-\gamma\left[\left(\frac{s_t - c}{\sigma_s}\right)\left(\frac{v_t - d}{\sigma_v}\right)\right]\right\},$$

where $s_t - c > 0$ and $v_t - c > 0$ are required, c and d are the minimum value of s_t and v_t . Noticeably, Hood and Dorfman (2015) were the first to introduce an observable economic indicator to the transition function.

STAR Model Specification

The STAR model we propose takes the following form based on the ECON-STAR model by Hood and Dorfman (2015):

$$(8) \Delta y_t = \psi'_1 \tilde{x}_t [1 - G(s_t; \gamma, c)] + \psi'_2 \tilde{x}_t G(s_t; \gamma, c) + \varepsilon_t,$$

where $\tilde{x}_t = (1, x_t, y_{t-1})$, $\psi'_1 = (0, \phi_1, 0)$, $\psi'_2 = (\phi_{2,0}, \phi_1, \theta_2)$, and where $\theta_2 < 0$ is required. We have modified the transition function to accommodate transition variables that represent the level of cattle inventories. Whereas the typical transition variable in the STAR model is defined as some average value of the model's dependent variable, the ECON-STAR model adopts an economic variable that is strongly connected to cattle prices. The empirical results from Hood and Dorfman (2015) have proven that sufficient demand is an important factor that ensures markets are linked. In this paper, we consider the role of supply in the market linkages. Therefore, controlling the effect of demand for cattle is needed. In our model, we use the adjusted level of cattle inventory that is defined as the annual level of cattle inventories over the corresponding annual level of disappearance of cattle, which is treated as the indicator of

demand for live cattle. This adjusted inventory in each of the observed time periods is the foundation of the model's transition function. Define the transition variable s_t as

$$(9) s_{it} = \frac{I_{it}}{D_t}, s_{jt} = \frac{I_{jt}}{D_t}.$$

Here I_{it} and I_{jt} denote the total cattle (including calves) inventories in state i and state j , respectively at time t , D_t is the number of slaughtered cattle in the U.S.

The resulting transition function is given by:

$$(10) G(s_{it}, s_{jt}; \gamma, \mu) = 1 - \exp[-\gamma * \Phi\left(\frac{s_{it}-\mu_i}{\sigma_i}\right) \Phi\left(\frac{s_{jt}-\mu_j}{\sigma_j}\right)],$$

where $s_t - c > 0$ is required. In equation (10), μ_i and μ_j are the mean values of the transition variables, s_{it} and s_{jt} , thus ensuring the required positivity, $s_t - \mu$ is normalized by σ to make the speed-of-adjustment parameter unit free, $\Phi(\cdot)$ is the cumulative density function of the standard normal distribution. The reason that we apply the cdf of a standard normal is that it exhibits nice properties for our purposes: it has flatter tails when the value goes to extremes and has almost linear movement for values within 2 standard deviations about zero. This property gives the model higher flexibility and a better description of how markets link and unlink over time. In the original ECON-STAR model of Hood and Dorfman (2015), the transition variable must go to zero at least once when its value reaches the minimum value, thus making a pair of states unlink at least once. However, by inserting the transition variable into a cdf, this problem is avoided since a cdf always returns a positive value. Additionally, when $G(s_t; \gamma, c) = 0$, the model goes to ψ_1 , which is a random walk. When $G(s_t; \gamma, c) = 1$, the model goes to ψ_2 , which indicates cointegration.

The lag length was set to $p=3$ for all models based upon both the AIC and BIC criteria. The speed-of-adjustment parameter, γ , is estimated to maximize the predictive strength of the final model. To estimate this parameter, we scanned over a range of γ values. For each fixed value of γ , the remaining parameters were estimated by maximum likelihood. The γ value that resulted in the highest likelihood function value was chosen as the estimate. This is equivalent to joint maximum likelihood of all the parameters. In our case, the speed-of-adjustment parameter value that maximizes the likelihood function also maximizes the R-squared model statistic, so we used this statistic to estimate the speed-of-adjustment parameter.

A maximum and minimum γ value constraint is imposed to restrict the speed-of adjustment parameter from going to zero or ∞ . The minimum γ value is set to 0.05 and the maximum γ value is set to 300. The smaller the parameter value the slower the two regions link and unlink, and the larger the parameter value the quicker the two regions adjust between linked and unlinked. The natural economic interpretation of the transition function is this: values equal to one indicate linked markets and values equal to zero indicate unlinked markets. Interpretation of values between the two extremes is more subjective, especially for intermediate values within this range.

Estimation and Results

Final Model Results

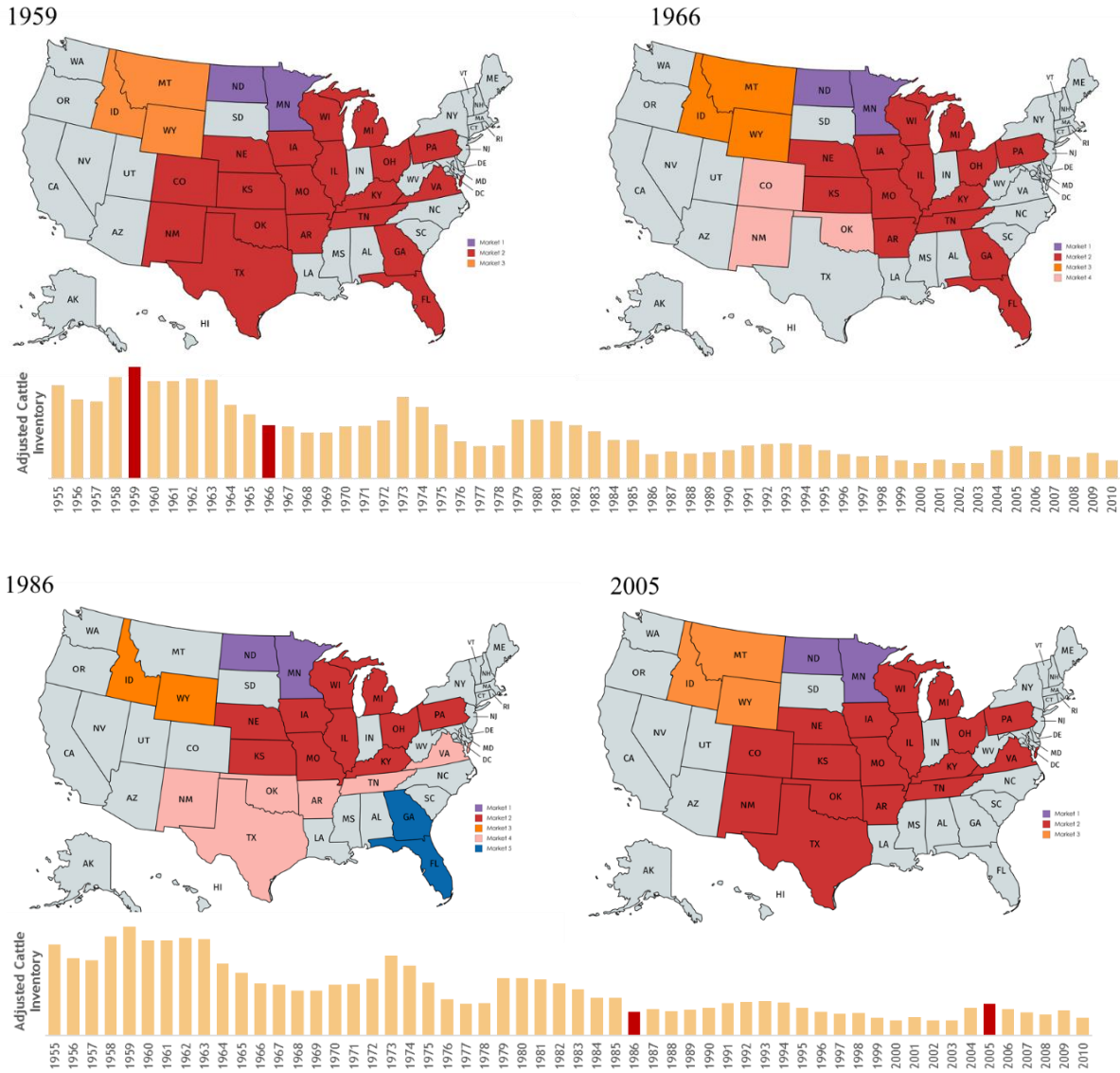
We evaluated 56 state-combinations using the above described model. Price pairs were selected to include all states that are contiguous to each other. The sample size is large enough to draw inference about market linkages among all regions evaluated. Results indicate that strong growth in the level of cattle inventory can cause numerous states to link together and function as one unified market.

We highlight 4 time periods (Figure 2) to show how cattle market linkages changed throughout the observed time period. We used $G(s_t; \gamma, c) \geq 0.9$ as the value required to signify market linkage. Results indicate that in 1959, when the adjusted level of inventory reaches an historic high, there were 3 distinct markets: 1) ND and MN; 2) CO, NM, NE, KS, OK, TX, IA, MO, AR, WI, IL, MI, OH, KY, TN, GA, FL, PA and VA; and 3) MT, ID, and WY. We observed 4 regional markets in 1966: 1) ND and MN; 2) NE, KS, TX, IA, MO, AR, WI, IL, MI, OH, KY, TN, GA, FL and PA; 3) MT, ID, and WY; and 4) CO, NM and OK. With the decrease in supply, we notice that CO, NM and, OK were separated from the original market. The size of the big central market is smaller compared with the pattern in 1959, and a new regional market emerged.

As the adjusted level of inventory dropped significantly in the 1980s, the cattle market became more segmented. In 1986, there are 5 distinct markets: 1) ND and MN; 2) NE, KS, TX, IA, MO, WI, IL, MI, OH, KY, and PA; 3) ID and WY; 4) NM, OK, TX, AR, TN and VA; and 5) GA and FL. Compared with the linkage pattern of 1959, CO and MT became isolated markets unlinked with any state. Moreover, AR and TN were separated from their previous market and formed a

new distinct market with VA, OK, MN and TX, while GA and FL unlinked with other markets and formed another regional market by themselves. For the entire time highlighted, the figure of 1986 marked the period when the market was most fragmented and had the fewest linkages.

Figure 4: Regional Linkage Over Time



More recently in 2005 when the adjusted level of inventory reached its peak in the 2000s, there were 3 distinct regional markets: 1) ND and MN; 2) CO, NM, NE, KS, OK, TX, IA, MO, AR, WI, IL, MI, OH, KY, TN, PA and VA; and 3) MT, ID, and WY. That is, Market 2 and Market 4 in 1986 linked as a whole market together with CO while MT joined Market 3. However, GA and FL were no longer linked with any state.

adjusts at a moderate rate between zero and one, the cointegration pattern between two states swing between linked and unlinked. For $\gamma \geq 20$, the transition function adjusts more quickly and there are extended periods of time in which the two markets are completely linked. The distribution of these estimated parameters is heavily weighted at the two tails, the cointegration between states tend to adjust either slowly or fast, but moderate speed adjustments are infrequently observed (Figure 7).

Figure 6: $G(s_{it}, s_{jt}; \gamma, \mu)$ Function Graphs of Select Price Pairs

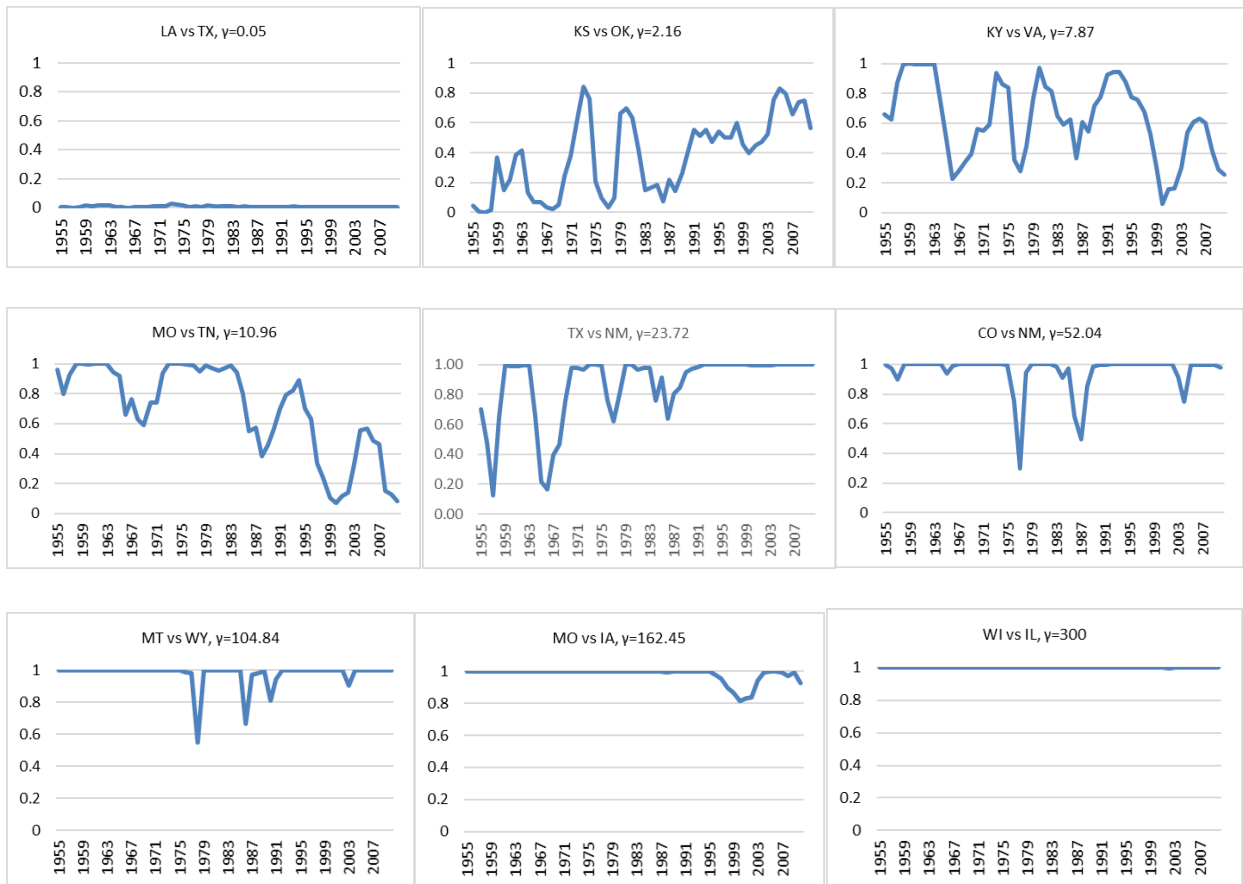
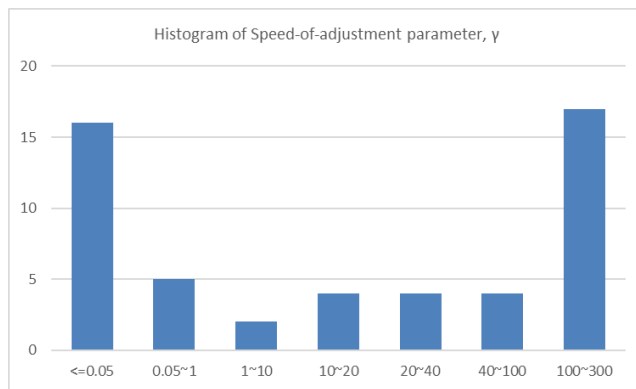


Figure 7: Histogram of γ Values for All Price Pairs



Conclusions

We have modified an ECON-STAR model with a flexible transition function to help us better understand cattle market relationships in U.S. By using adjusted cattle inventories as transitional variables, we can see that excess supply can cause numerous regions and states to link together and function as a whole market. When a surplus occurs, agents in the market are more motivated to seek profits which then leads to increased trade amongst multiple markets. We find that in the 1950s - the peak of cattle inventory in the U.S. history- apart from two small regional markets, the entire middle and south markets are linked. On the contrary, after the mid-1980s, as inventories fell to their lowest levels, the markets became segmented and some of the states exhibited no integrating relationships. Moreover, after 2003, the relative cattle supply rebounded a little, which may cause numerous regions and states to link together and function as one unified market again.

Apart from the low level of inventory, a possible reason for recently segmented cattle market is the heterogeneity of beef quality. Empirical results (Lusk and Norwood, 2005) indicate that supply and demand shifts have the potential to alter the average quality of beef on the market. When the assumption of homogeneous products is violated, we will see more segmented markets. For this reason, when two states are not linked, it does not necessarily mean there is no trade of cattle between these two states. There could be numerous trading of quality-differentiated cattle among “unlinked” states.

This paper makes a key contribution to the theoretical literature by modifying a form of ECON-STAR model in which the transition functions better deal with economic indicators at the extremely low value. The article also contributes to the understanding of price cointegration of cattle markets by mapping when different regional markets have been linked economically. The empirical results show how important sufficient supply and profit-seeking behavior are to ensure markets are linked.

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