Arbitrage Costs Between Regional Fed-Cattle Markets

by

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Arbitrage cost models were used to measure the degree of integration between regional geographic AMS reported fed cattle markets. The method measures the implicit arbitrage costs and probability of arbitrage between two markets, and is also used to test the 5% rule from the Federal Trade Commission and Department of Justice Merger Guidelines. The results suggest that all U.S. fed cattle markets are well integrated. However, there are degrees of integration. East coast and west coast markets are distinct from markets in the central U.S. Further, arbitrage costs are lower from small volume markets to large markets, while costs are higher from large to small markets. Thus, for antitrust analysis, large market regions may be considered in isolation while small regions should include neighboring large regions in the economic market definition.

Introduction

Monitoring fed cattle pricing competitiveness and enforcement of the Packers and Stockyards Act require identification of regional economic market boundaries. Determining the relevant market is a first step in analyzing industry structure and performance, and in reviewing the economics of antitrust questions. Economic market boundaries identify separate geographic areas within which partial equilibrium analyses are valid and where a firm may impose significant and nontransitory changes in price through noncompetitive conduct.

While the concept of an economic market may be different from that of an antitrust market, a delineation necessary for antitrust action following the Merger Guidelines of the Federal Trade Commission and Department of Justice, the two concepts are closely related. Economic markets are defined by arbitrage while antitrust markets are defined by the ability of economic agents to exercise market power. An antitrust market for an oligopsony will be smaller or larger than the local economic market depending on the elasticities of demand for each oligopsonist. However, defining economic markets is a useful first step for the more detailed procedure of identifying antitrust markets.

The relevant geographic market for antitrust analysis is often based on product flows of firms transacting in the same and closely related products (Elzinga and Hogarty). The classic procedures for market delineation involve estimating cross elasticities (Scherer) or own price elasticities for residual demand functions (Scheffman and Spiller). These measurements determine which firms have sufficiently strong direct effects on product flows; cross supply elasticities delineate procurement areas and own price elasticities identify price takers. This approach can identify economic and antitrust markets. However, elasticity procedures are often impractical due to unavailability of product data. Price data are more common and price correlations have been relied on as one tool to characterize product, firm, or geographic market

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relationships (Stigler and Sherwin). However, correlation findings may be misleading in markets where the common supply and demand factors influence prices more then arbitrage.

An alternative procedure, which uses publicly available price data but which also addresses the weakness of price correlations, involves estimating arbitrage cost models. Implicit arbitrage costs can be estimated using historical price differences. Observed prices from various geographic areas will contain information about the cost of arbitrage between the areas and the size of these costs can be estimated. While arbitrage does not necessarily eliminate market power, low arbitrage costs across geographic areas do imply the existence of a larger economic market while high arbitrage costs imply some degree of market segmentation. This research takes this alternative approach. Arbitrage cost models are used to identify regional fed cattle market boundaries between USDA AMS Market News price reporting districts. A comprehensive analysis of publicly available fed cattle price data is performed.

Previous Research

Considerable literature has examined regional price dynamics in fed cattle markets. This research has been conducted within the context of efficient markets and price discovery. The objective has been to determine the relative effectiveness of different markets in incorporating information into price. Research on regional price dynamics also provides information on the extent of geographic markets.

Bailey and Brorsen, Koontz, et al., Schroeder and Goodwin, and Goodwin and Schroeder (1991) have all used various time series methods to examine the dynamic interactions of various USDA AMS reported weekly fed cattle prices during the late-1970s and 1980s. All studies found that prices of large markets in the midwest and plains states were closely linked and lead price discovery. Few studies have examined actual product flows. Schultz used trade area cross elasticities to analyze the relevant market for fed cattle. She concluded that the Midwest-Texas market seemed to constitute a relevant market, with weaker ties to coastal regions. However, the quantity data were limited.

Although high correlations can delineate markets, this analysis may not be conclusive. For example, common influences affect the price of fed cattle, e.g., variation in wholesale beef prices, which could contribute to high correlations. It is difficult to determine if co-movements in prices occur because the different areas are in the same economic market, because there is arbitrage between regions, or because the regions experience common changes in supply and demand conditions. This is a significant shortcoming of existing research.

Arbitrage cost models were developed due to the lack of quantity data for many products. Further, the method examines discontinuous relationships between differences in geographic prices, as opposed to the continuous linear measures of price changes. These models have been used to assess boundaries for regional wholesale gasoline markets (Spiller and Huang; Spiller and Wood) and test integration of U.S. celery markets (Sexton, et al.).

Method and Procedures

The statistical model uses spatial equilibrium arbitrage conditions to specify a parametric relationship between regional prices. The spatial equilibrium arbitrage conditions state that, if the difference between two regional prices is large enough to cover arbitrage costs, the price in the high-price region must equal the price in the low-price region plus arbitrage costs. If the difference is less than arbitrage costs, price movements may be unrelated or related due to changes in common supply and demand conditions. There is no explicit use of transaction cost data in the model. Rather, implied arbitrage costs are revealed by how large the difference between the two prices becomes and the frequency of these large differences.

The difference between prices in two regions, 1 and 2, between which there is no arbitrage, is assumed constant but stochastic

$$(1) \qquad Y_t = P_{1t} - P_{2t} = \alpha + \epsilon_t$$

where the error term captures relative differences in local supply and demand shocks, is identically and independently distributed, and has a zero mean and variance σ^2. The subscript *t* denotes time. This is the relationship between prices in two markets where no arbitrage occurs. Transaction costs have a distribution restricted to positive values

$$(2) \qquad T_{it} = T_i^* + \epsilon_{it} > T_i^k \geq 0 \quad \text{for } i=1,2$$

where T_{it} represents stochastic arbitrage costs from region *i* to *j* with mean T_i^* and T_i^k is the lower bound. Arbitrage occurs only if the price difference exceeds transaction costs. In this case, the equilibrium price difference equals those costs. If the price difference is small, no arbitrage takes place and the equilibrium price difference equals α. There are three mutually exclusive regimes:

$$(3) \qquad \begin{array}{lll} \text{Arbitrage from 2 to 1:} & P_{1t} - P_{2t} = T_2^* + \epsilon_{2t} & \text{if } Y_t \geq T_{2t} \\ \text{Arbitrage from 1 to 2:} & P_{1t} - P_{2t} = -T_1^* - \epsilon_{1t} & \text{if } Y_t \leq -T_{1t} \\ \text{No binding arbitrage:} & P_{1t} - P_{2t} = \alpha + \epsilon_t & \text{if } -T_{1t} < Y_t < T_{2t}. \end{array}$$

The probability that each regime occurs is as follows:

$$(4) \qquad \begin{array}{l} \lambda_1 = \text{Prob}\{\epsilon_t - \epsilon_{2t} \geq -\alpha + T_2^*\} \\ \lambda_2 = \text{Prob}\{\epsilon_t + \epsilon_{1t} \leq -\alpha - T_1^*\} \\ \lambda_3 = \text{Prob}\{-T_1^* - \epsilon_{1t} < \alpha + \epsilon_t < T_2^* + \epsilon_{2t}\} = 1-\lambda_1-\lambda_2. \end{array}$$

The probability of observing arbitrage $(\lambda_1+\lambda_2)$ is a function of the arbitrage cost distributions and the distribution of supply and demand shocks when no arbitrage occurs. With assumptions about the distribution of ϵ_t, ϵ_{1t}, and ϵ_{2t}, the model can be estimated. Previous applications have assumed ϵ_t is distributed normal and ϵ_{it}, $i=1,2$, are distributed truncated normal or gamma. The gamma distribution was found to work best in this application so the remainder of the discussion is limited to this specification.

When transaction costs follow a gamma distribution, $T_{it} \sim \text{gamma}(\alpha_i, \beta_i \mid T_{it}>0)$, the mean of the transaction cost distribution of arbitrage from region *i* to region *j* is

$$\text{(5a)} \quad E(T_{it}) = \alpha_i \cdot \beta_i$$

and the variance of the transaction cost distribution is

$$\text{(5b)} \quad V(T_{it}) = \alpha_i \cdot \beta_i^2.$$

The distribution is truncated at zero. Assuming independence of ϵ_t, ϵ_{1t}, and ϵ_{2t}, the likelihood function of the arbitrage cost model is

$$\text{(6)} \quad L = \prod_{t=1}^{N} \{\lambda_1 f_{1t} + \lambda_2 f_{2t} + (1-\lambda_1-\lambda_2) f_{3t}\}$$

where

$$\text{(6a)} \quad \lambda_1 = \int_0^{\infty} [1 - \Phi((u-\alpha)/\sigma)]\, u^{\alpha_2 - 1} \exp\{-u/\beta_2\} \,/\, \beta_2^{\alpha_2} \Gamma(\alpha_2)\, du$$

$$\text{(6b)} \quad \lambda_2 = \int_0^{\infty} [1 - \Phi((u-\alpha)/\sigma)]\, u^{\alpha_1 - 1} \exp\{-u/\beta_1\} \,/\, \beta_1^{\alpha_1} \Gamma(\alpha_1)\, du$$

and

$$\text{(6c)} \quad f_{1t} = Y_t^{\alpha_2} \exp\{-Y_t/\beta_2\}/[\beta_2^{\alpha_2} \Gamma(\alpha_2)]$$

$$\text{(6d)} \quad f_{2t} = Y_t^{\alpha_1} \exp\{-Y_t/\beta_1\}/[\beta_1^{\alpha_1} \Gamma(\alpha_1)]$$

$$\text{(6e)} \quad f_{3t} = \phi[(Y_t - \alpha)/\sigma]/\sigma$$

where $\Gamma(\cdot)$ is the incomplete gamma function, and $\phi(\cdot)$ and $\Phi(\cdot)$ are the standard normal density and distribution functions. The probability of arbitrage from market *i* to market *j* (λ_j) depends on parameters of the arbitrage cost distribution (α_i and β_i). This restriction is incorporated into the model through equations (6a) and (6b).

Estimates of the parameters in (6) were obtained by maximizing the logarithm of the likelihood function. The MAXLIK routine (version 2.01) in the software package GAUSS-386 (version 2.2) was used. Numerical methods were used to calculate gradient vectors and Hessian matrices and to integrate equations (6a) and (6b). Asymptotic standard errors were calculated for the parameter estimates using White's method which uses the cross-product of the gradient vector and the inverse of the negative Hessian matrix.

The results of interest for defining economic market boundaries are the arbitrage cost parameters and the probabilities of arbitrage. Estimates of the arbitrage cost parameters help identify whether different areas were likely to be contained in the same economic market if prices in one of the regions changed sufficiently. Low costs suggest the areas in question are contained in the same economic market. High costs suggest some degree of economic market separation. Estimates of the probability of arbitrage help identify which regions frequently face binding arbitrage conditions. Arbitrage is expected to be infrequent between neighboring areas and more frequent between areas which are geographically more separate.

The model is also used to test the 5% rule in the Federal Trade Commission and Department of Justice Merger Guidelines. The probability that no arbitrage occurs from market 1 to market 2 when the price in market 1 is 5% below the price in market 2 is calculated as follows. The 5% price difference implies

$$(7) \qquad Y_t^* = P_{1t} - P_{2t} - \alpha = 0.95P_{2t} - P_{2t} - \alpha = -0.05P_{2t} - \alpha.$$

The average difference in market prices when there is no arbitrage (α) is included to allow for different levels of excess supply and demand between the regions. Following Kiefer, this series is used with the maximum likelihood estimates to calculate the probability that each observation is in regime 2, i.e., arbitrage from market 1 to market 2

$$(8) \qquad \omega_t = \lambda_2 f_{2t}(Y_t^*) \,/\, (\lambda_1 f_{1t}(Y_t^*) + \lambda_2 f_{2t}(Y_t^*) + \lambda_3 f_{3t}(Y_t^*)).$$

The probability that arbitrage occurs between the two markets is the sample average of ω_t. The probability that arbitrage does not occur between the two markets is one minus this sample average. A large probability of no arbitrage implies the two markets are segmented and do not pass the 5% rule. A small probability of no arbitrage implies the two markets are in the same economic market according to the 5% rule.

Data

Data used were obtained from USDA AMS LS-214 reports. Daily fed cattle price ranges for several terminal markets and all direct trade regions within the continental U.S. were used. The specific regional direct trade regions include:

- Illinois,
- Iowa and Southern Minnesota,
- Eastern Nebraska (eastern two-thirds of the state),
- Western Nebraska, Wyoming, and Southwest South Dakota,
- Colorado,
- Eastern Kansas,
- Western Kansas,
- Texas, Oklahoma, and New Mexico
- Arizona,
- Southern California (El Centro - Desert Area),
- Central California (Visalia - Southern San Joaquin Valley),
- Washington and Oregon, and
- Idaho.

value for the arbitrage cost model is the same as the likelihood value of the model without arbitrage. Failure of the model to estimate arbitrage costs suggests these pairs of geographic areas are in the same economic market or are completely separate markets.[1]

Average arbitrage costs between markets are reported in Table 1. The probabilities of binding arbitrage between markets (λ_1 and λ_2) are reported in Table 2. Table 3 reports the probabilities of not observing arbitrage between two markets when the price in the market on the vertical axis is 5% below the price in the market on the horizontal axis. These are the three sets of measures that are crucial for determining economic market boundaries.

In general, means of the arbitrage costs are small. The estimates are between 1% and 5% of the average price level. Distances between each market were identified and transportation costs were calculated based on a $0.40/cwt./100 miles variable cost figure. The arbitrage cost estimates were approximately equal to transportation cost figures for pairs of neighboring markets. For example, the distance between Western Kansas (Liberal) and Texas (Amarillo) is approximately 200 miles, the transportation cost is $0.80/cwt., and the arbitrage cost estimates are $0.89/cwt. from Western Kansas to Texas and $0.66/cwt. from Texas to Western Kansas. The majority of the implicit arbitrage cost estimates were well below the transportation cost figures. Arbitrage cost estimates are small relative to the transportation costs because there is demand for fed cattle in all of the geographic areas. Arbitrage costs are small relative to the transportation costs in neighboring areas because of the contiguous nature of cattle feeding. Transportation costs were calculated based on a distance between two cities while arbitrage occurs somewhere between the two locations.[2] The small estimated arbitrage costs suggest that all of the U.S. fed cattle markets are reasonably well linked. The linkage is due to an indirect relationship through a relatively national market for fresh beef and the national transportation infrastructure. There are no geographic areas in the continental U.S. which are completely separate economic markets. However, the results also show that there is variation in the strength of the linkage between geographic areas.

Much of the variation in market integration appears in arbitrage cost asymmetry. The distance between two geographic areas is symmetric. Asymmetric arbitrage costs imply it is more costly to ship cattle one direction than the other. This implies market separation.[3] For example, the arbitrage cost estimates are $1.72/cwt. from Idaho to Texas and $3.13/cwt. from Texas to Idaho. Both of these figures are much lower than the transportation costs, but the asymmetry suggests that, within the national market for fed cattle, the Texas price achieves a much lower discount to the Idaho price before regional flows of cattle change. Idaho achieves

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1 Co-integration and causality tests were conducted between each of these pairs of markets. All pairs are co-integrated and exhibit significant causality, and most exhibit bi-directional causality. The weakest relationship was between Arizona and Idaho.

2 The cities chosen were in the center of the largest area of production within each geographic region.

3 Further, direction of the asymmetry is inconsistent with reducing costs by backhauling.

a smaller discount to Texas before regional flows of cattle change. This is one of the more pronounced cases, but similar asymmetries occur between markets in the desert southwest (Southern California and Arizona) and markets in the plains states (Western Nebraska, Colorado, Western Kansas, and Texas) and midwest markets west of the Mississippi River (Eastern Nebraska and Eastern Kansas). Likewise, there are asymmetries in arbitrage costs between plains states markets and midwest markets. Plains states markets achieve larger discounts to midwest markets than the reverse; the results show it is more costly for the plains markets to ship cattle to the midwest than for the midwest to ship cattle to the plains. The asymmetry has structure. The results show costs are lower for a smaller volume market to ship cattle to a larger market with higher regional meatpacking plant capacity, while it is more costly for larger markets to ship cattle to smaller markets. This structure would mitigate the exercise of market power in smaller markets but suggests that smaller regional markets need not be considered part of the relevant market when examining market power in the larger regional markets.[4]

The probabilities of observing arbitrage (Table 2) are, for the most part, also relatively small. The distribution of fed cattle across markets does not change often because arbitrage conditions are not triggered often, even given the relatively low average arbitrage costs. However, the standard errors of these estimates are very low suggesting that arbitrage conditions do occur. Arbitrage is necessary to link the system of markets together. For example, the probability of arbitrage from Western Kansas to Texas is 7.5%, while arbitrage from Texas to Western Kansas occurs 7.6% of the time. The probabilities are all very small within and between the group of markets in the plains states and the group of markets in the upper midwest.

The probabilities are much larger and asymmetric between these two groups of markets in the central U.S. and the east coast market, the southwest markets, and the Pacific northwest markets. For example, the probability of arbitrage from Texas to Idaho is 4.7% while arbitrage from Idaho to Texas occurs 28.4% of the time. The probability of arbitrage from Washington to Idaho is 4.7% while the probability of arbitrage from Idaho to Washington is 20.5%. The structure of the asymmetry is similar to that of the mean arbitrage costs. It is more costly for large volume markets to ship cattle to smaller markets, therefore arbitrage occurs infrequently, and where the arbitrage costs are low, arbitrage occurs more frequently. The probability results lead to similar conclusions. There is a separation of markets on the coasts from markets in the central U.S. There is also some separation between markets within the southwest and northwest. Larger volume areas need to be studied in isolation whereas the smaller volume areas should include the neighboring larger areas.

The probability of no arbitrage results generated from the 5% rule (Table 3) complement the other findings. To determine whether or not effective arbitrage occurs with a 5% decrease in one market price, the probability estimate is compared to 0.5 (Lee and Porter). When the

4 This conclusion should also apply to the delineation of antitrust markets. In the context of Scheffman and Spiller, demand for fed cattle within the smaller capacity regions should be more inelastic than demand by meatpackers in larger capacity regions. Therefore, the relevant antitrust market for the larger region may not include the smaller region while the smaller region would include the larger.

probability of no arbitrage is significantly larger than 50%, this implies segmented markets. A probability significantly less than 50% implies a single market. The standard errors of the probabilities are roughly 0.05. If the probability is 45% or less (≈ 1 standard error), the conclusion is that arbitrage occurs. If the probability is 68% or greater (≈ 3 standard errors), the conclusion is that arbitrage does not occur. This cautious interpretation errs toward finding larger economic markets and is necessary to draw conclusions from the results.

When the price in Pennsylvania is reduced 5% there is no effective arbitrage with any of the other market prices. Further, we can conclude there will be no arbitrage linking Pennsylvania with Colorado, Western Kansas, Texas, and Southern California. Pennsylvania is a separate economic market. Likewise, Arizona, Southern California, Central California, Washington, and Idaho each display evidence of being a reasonably separate economic market. Arizona and Southern California display strong separation from the Illinois, Omaha, and Sioux City markets. Central California displays strong separation from the Iowa, Eastern Nebraska, Eastern Kansas, and plains markets. Washington and Idaho display strong separation from Pennsylvania. However, prices of fed cattle in Idaho are arbitraged with the terminal market prices, and Washington is arbitraged with the upper midwest markets of Eastern Nebraska and Eastern Kansas, and the northern plains markets of Western Nebraska and Colorado. Upper midwest and northern plains cattle will move to the Pacific northwest with a 5% price difference. The reverse does not occur.

The upper midwest geographic areas of Illinois, Iowa, Eastern Nebraska, Eastern Kansas, Omaha, and Sioux City appear to be an economic market, and the plains states geographic areas of Western Nebraska, Colorado, Western Kansas, and Texas also appear to be an economic market. There is effective arbitrage from some of the upper midwest markets to the plains states markets, in particular from Illinois to Western Kansas, and from Eastern Nebraska to Western Kansas and Texas. However, there is little arbitrage from plains markets to midwest markets, and the arbitrage is not uniform between geographic areas of the two groups, while the arbitrage is very uniform between markets within each group.

While a 5% reduction in fed cattle prices is substantial, it is not large enough to initiate much arbitrage. It is interesting that a 5% reduction in price in many of the geographic areas does little to change regional flows of cattle. While the average arbitrage cost is relatively small, there appears to be enough variability in cost and arbitrage occurs infrequently enough that price in many fed cattle markets can be reduced 5% with little effect. However, the model uses daily observations so any price reduction likely will occur only for short time periods.

Summary and Conclusions

This research is a comprehensive examination of geographic arbitrage costs as revealed in publicly reported fed cattle price data. The work identifies the extent of economic markets within the set of geographic fed cattle areas and helps identify regions within which there is the greatest potential for the exercise market power. This information on the extent of regional economic markets is useful for focusing monitoring activities and executing public policy.

The estimated distributions of arbitrage costs were compared to transportation cost estimates. High arbitrage costs imply market isolation, separate economic markets, and an increased likelihood of market power. Estimated arbitrage costs were examined for symmetry between markets. The potential for exercise of market power is higher in a geographic area which is costly to arbitrage. The models reveal probabilities that various geographic areas do not exhibit direct arbitrage (i.e., the degree to which markets are separate) and the probability that direct arbitrage occurs (i.e., the two geographic areas are the same economic market). Also, the probability that reducing a price 5% will cause arbitrage from other regions was examined. This is a direct assessment of the potential for abusive market power as defined by the Federal Trade Commission and Department of Justice Merger Guidelines.

The means of the arbitrage costs are small. The estimates are between 1% and 5% of the average price level. The arbitrage cost estimates were below the transportation cost estimates. The results suggest that all of the U.S. geographic fed cattle price reporting regions are reasonably well linked into a national fed cattle market. However, the markets are not perfectly integrated. There are some areas which form reasonably separate economic markets. Costs are lower for arbitrage from smaller volume markets to larger markets. It is much more costly for larger volume markets to ship cattle to smaller volume markets. This appears to be related to the level of regional meatpacking plant capacity. Arbitrage mitigates the exercise of market power in smaller markets but suggests that smaller regional markets should not be considered part of the relevant market when examining market power in the larger markets.

The probabilities of arbitrage are also small, especially within and between the group of markets in the plains states and the group in the upper midwest. However, arbitrage does link these groups together. Arbitrage probabilities are much larger and more asymmetric between markets in the central U.S. and markets on the east coast, markets in the southwest, and markets in the northwest. The interpretation is the same as with the mean arbitrage costs. There is a separation of markets on the coasts from markets in the central U.S. and larger volume market areas need to be studied as separate markets, whereas the smaller volume market areas should include the neighboring larger volume markets within their relevant market definition.

The test of the 5% rule confirms the east and west coasts are separate economic markets. The upper midwest markets appear to be an economic market and the plains states markets also appear to be an economic market. There is arbitrage from the upper midwest to the plains states. However, there is little arbitrage from plains states to the midwest. Arbitrage is uniform between markets within each of these two groups. The test also suggests that, for a period of one day to one week, it is relatively easy for price in many of the geographic areas to be reduced by 5% with little change in the regional flows of cattle.

A summary of how relevant economic markets should be defined for antitrust actions is as follows. Antitrust actions in the plains states should consider only the plains states markets. Actions in the upper midwest markets should consider those markets and the plains states markets. Actions in the desert southwest and California should consider each market individually or the markets as a group. Actions in the Pacific northwest should consider markets in the northern plains and markets in the upper midwest west of the Mississippi River. Actions in the northeast should consider only east coast markets.

Table 1. Mean Transaction Costs ($/cwt. fed cattle) of Arbitrage from Market x to Market y.

x \ y	Penn	Illi	Omah	Siou	Iowa	ENeb	WNeb	Colo	EKan	WKan	Texa	Ariz	SCal	CCal	Wash	Idah
Penn		1.53	1.69	1.78	1.62	1.49	1.56	1.40	1.15	1.20	1.14	2.12	1.52	1.84	1.72	1.75
Illi	1.56		1.13	1.15	1.20	1.26	1.42	1.43	0.94	1.39	1.15	1.30	1.22	2.19	1.85	1.78
Omah	1.39	0.84		0.80	0.84	0.93	1.10	1.07	1.21	0.89	0.99	2.17	2.10	2.06	1.57	1.49
Siou	1.63	1.05	0.97		0.99	1.12	1.28	1.28	1.19	0.96	1.00	2.27	1.20	2.14	1.78	1.72
Iowa	1.20	----	0.78	0.88		0.93	1.20	1.27	1.16	1.01	1.10	2.26	2.28	2.01	1.61	1.73
ENeb	1.26	0.79	0.79	0.87	0.82		0.91	1.08	1.05	1.00	1.12	2.18	2.24	2.08	1.64	1.98
WNeb	1.31	0.96	0.87	0.99	0.95	0.93		1.01	0.78	0.89	1.04	2.14	2.22	2.09	1.45	2.05
Colo	1.26	0.86	0.87	0.88	0.90	0.94	0.76		0.86	----	1.07	2.20	2.15	2.04	1.60	2.53
EKan	1.15	0.80	----	----	0.93	1.04	0.73	0.70		----	----	1.68	1.80	2.02	1.57	2.41
WKan	1.14	----	0.77	0.86	0.84	0.84	----	----	----		0.89	2.27	2.29	2.15	2.55	2.82
Texa	1.20	0.65	0.79	0.83	0.85	0.82	----	----	----	0.66		2.09	2.07	2.39	2.60	3.13
Ariz	1.83	1.27	1.56	1.69	1.87	1.75	1.79	1.81	1.26	1.89	1.77		1.09	1.96	1.64	----
SCal	1.72	1.32	1.68	1.53	1.79	1.76	1.84	1.81	1.21	1.93	1.78	1.14		1.88	1.73	1.65
CCal	1.90	1.80	1.80	1.73	2.08	2.04	1.94	2.05	2.20	2.28	2.21	1.81	1.86		1.44	1.45
Wash	1.51	1.21	1.30	1.24	1.50	1.47	1.35	1.38	1.43	1.64	1.58	1.62	1.65	1.32		2.20
Idah	1.70	1.47	1.35	1.31	1.59	1.51	1.47	1.51	1.40	1.70	1.72	1.97	1.87	1.43	1.16	

Table 2. Probability of Arbitrage from Market x to Market y.

x \ y	Penn	Illi	Omah	Siou	Iowa	ENeb	WNeb	Colo	EKan	WKan	Texa	Ariz	SCal	CCal	Wash	Idah
Penn		0.251	0.196	0.238	0.171	0.173	0.180	0.173	0.160	0.142	0.142	0.427	0.227	0.287	0.216	0.267
Illi	0.258		0.097	0.145	0.075	0.053	0.070	0.071	0.058	0.070	0.060	0.219	0.224	0.257	0.135	0.168
Omah	0.239	0.118		0.168	0.074	0.066	0.104	0.096	0.115	0.065	0.067	0.187	0.188	0.232	0.160	0.207
Siou	0.264	0.161	0.184		0.064	0.060	0.082	0.077	0.092	0.062	0.067	0.179	0.235	0.250	0.136	0.173
Iowa	0.219	----	0.080	0.068		0.082	0.138	0.118	0.115	0.080	0.083	0.237	0.222	0.259	0.208	0.178
ENeb	0.197	0.061	0.068	0.065	0.089		0.137	0.114	0.103	0.068	0.078	0.258	0.232	0.228	0.198	0.120
WNeb	0.208	0.087	0.119	0.098	0.170	0.151		0.070	0.048	0.055	0.074	0.269	0.240	0.215	0.224	0.100
Colo	0.186	0.094	0.110	0.096	0.153	0.128	0.074		0.067	----	0.066	0.245	0.250	0.203	0.190	0.060
EKan	0.163	0.062	----	----	0.138	0.107	0.051	0.068		----	----	0.183	0.173	0.207	0.154	0.069
WKan	0.149	----	0.072	0.065	0.091	0.075	----	----	----		0.075	0.218	0.209	0.195	0.069	0.064
Texa	0.140	0.069	0.074	0.072	0.097	0.091	----	----	----	0.076		0.213	0.214	0.151	0.059	0.047
Ariz	0.430	0.226	0.233	0.206	0.245	0.287	0.262	0.258	0.224	0.275	0.284		0.113	0.167	0.202	----
SCal	0.207	0.217	0.215	0.203	0.254	0.273	0.245	0.265	0.235	0.271	0.295	0.114		0.193	0.190	0.249
CCal	0.275	0.262	0.266	0.281	0.248	0.264	0.264	0.261	0.241	0.257	0.251	0.252	0.248		0.127	0.157
Wash	0.238	0.193	0.189	0.184	0.223	0.235	0.247	0.276	0.184	0.261	0.269	0.214	0.206	0.138		0.048
Idah	0.269	0.191	0.235	0.220	0.235	0.250	0.236	0.263	0.300	0.291	0.284	0.181	0.237	0.161	0.205	

Table 3. Probability of No Arbitrage from Market x to Market y if the Price in Market x is 5% Below the Price in Market y.

x \ y	Penn	Illi	Omah	Siou	Iowa	ENeb	WNeb	Colo	EKan	WKan	Texa	Ariz	SCal	CCal	Wash	Idah
Penn		0.62	0.64	0.65	0.65	0.68	0.67	0.70	0.67	0.72	0.72	0.51	0.70	0.64	0.68	0.63
Illi	0.63		0.37	0.44	0.01	0.36	0.42	0.48	0.11	0.42	0.60	0.68	0.69	0.49	0.57	0.48
Omah	0.70	0.70		0.49	0.44	0.42	0.40	0.46	0.19	0.55	0.55	0.66	0.67	0.55	0.48	0.44
Siou	0.68	0.58	0.50		0.45	0.42	0.45	0.48	0.40	0.62	0.65	0.69	0.70	0.52	0.52	0.45
Iowa	0.75	----	0.59	0.59		0.42	0.37	0.37	0.44	0.47	0.49	0.54	0.58	0.54	0.47	0.49
ENeb	0.73	0.72	0.60	0.63	0.60		0.44	0.42	0.49	0.43	0.40	0.49	0.54	0.56	0.44	0.49
WNeb	0.72	0.67	0.64	0.63	0.64	0.57		0.37	0.26	0.01	0.03	0.47	0.52	0.55	0.43	0.50
Colo	0.72	0.75	0.66	0.72	0.71	0.61	0.65		0.39	----	0.01	0.46	0.48	0.58	0.44	0.58
EKan	0.70	0.69	----	----	0.69	0.66	0.69	0.74		----	----	0.68	0.66	0.61	0.45	0.54
WKan	0.71	----	0.66	0.60	0.66	0.63	----	----	----		0.34	0.49	0.52	0.58	0.59	0.58
Texa	0.66	0.85	0.68	0.65	0.70	0.70	----	----	----	0.66		0.47	0.50	0.57	0.60	0.63
Ariz	0.57	0.84	0.69	0.69	0.65	0.64	0.64	0.65	0.51	0.67	0.65		0.49	0.56	0.63	----
SCal	0.70	0.80	0.69	0.71	0.66	0.64	0.65	0.65	0.51	0.67	0.65	0.51		0.56	0.64	0.63
CCal	0.67	0.67	0.67	0.66	0.70	0.69	0.68	0.69	0.73	0.71	0.70	0.61	0.63		0.61	0.58
Wash	0.70	0.68	0.60	0.64	0.61	0.60	0.61	0.60	0.58	0.55	0.52	0.65	0.66	0.58		0.49
Idah	0.69	0.59	0.57	0.61	0.56	0.54	0.53	0.49	0.55	0.56	0.53	0.53	0.66	0.55	0.48	

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