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Spatial Price Dynamics in U.S. Regional Broiler Markets

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The U.S. broiler industry is highly vertically integrated and increasingly concentrated in the number of firms and production areas. These structural elements could have implications for performance and the functioning of the law of one price (LOP) across regions. This article investigates this using data on four regional markets. Cointegration results indicate that regional prices are spatially linked in the long run, but pairwise cointegration was not found, suggesting that the LOP does not hold. Causality tests confirm the relative importance of price shocks from the South. This finding is reflective of price coordination by firms with production in multiple regions.

Key Words: broiler prices, causality, cointegration, market integration

JEL Classifications: Q13, D43, C22

Several researchers have investigated the performance and market efficiency of various agricultural commodities by studying the nature of the price relationships among spatially separated markets (Baulch; Bessler and Fuller; B.K. Goodwin and Piggott; B.K. Goodwin and Schroeder; Sexton, Kling, and Carman). A majority of these studies have focused on the international wheat market and the livestock (cattle and hog) industry. However, previous studies of the broiler industry have yet to focus on analyses of spatial price relationships but have emphasized other related issues, such as the demand for poultry products (Chavas; Eales and Unnevher; Thurman) and the transmission of poultry market price signals across marketing channels (Bernard and Willet; H.L. Goodwin, McKenzie, and Djunaidi). Given the importance of the poultry sector and the rapidly changing structure of the industry, there is a need for a closer analysis of its performance. Thus, this study examined broiler-market price linkages by studying the effect of price shocks in one region on other regional broiler markets.

Although the U.S. broiler industry has long been highly vertically integrated, it has become increasingly concentrated over the past decade. Vertically integrated poultry firms now account for approximately 95% of total broiler production via contracting and, to a limited extent, through direct ownership (H.L. Goodwin). The four-firm concentration ratio is 56%, with the largest broiler producers being Tyson, Pilgrim's Pride, Gold Kist, and Perdue. This compares with a concentration ratio of 46% a decade earlier and around 35% another decade before that (Hendrickson and Heffernan). The increased level of industry concentration could be attributed to internal economy of scale via improved production efficiency, increase in the percentage of value-added products, and higher prevalence of mergers and acquisitions in the broiler industry (H.L. Goodwin; Ollinger, MacDonald,

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and Madison). In addition, the industry is highly geographically concentrated, allowing the possibility for price relationships between high- and low-production regions to vary. Together, these market trends suggest possible reasons for recent interest in the industry's structure and concern over its impact on market price dynamics. The extent of regional broiler price linkages and market integration in different wholesale broiler markets could be influenced significantly by the industry's market structure in terms of production and marketing contracts (B.K. Goodwin, McKenzie, and Djunaidi).

In the current industry structure, the large broiler firms (integrators) control the product from selection of the strain of bird to retail distribution of ready-to-cook and other processed products. This includes ownership of the breeders, hatchery, feed mill, and processing plants. However, the broiler firms contract with farmers for their supply of broilers. Although integrators provide the growers with production inputs, such as feed, hatcheries, and veterinarian services, the growers are responsible for providing other inputs, such as labor, equipment, and housing facilities. In contrast to the variations in the turkey and egg industries, the pattern of contracting in the broiler industry is quite similar across the country. Production contracts are such that growers receive a minimum payment per pound, per bird (or per unit of space) with incentives for performance. These incentives are usually based on deviations from average performance during a specified period. These contracts reduce the grower's exposure to price risks compared with a fully market-coordinated system.

In addition to contracting with broiler growers on the production side, the integrators also engage in contracting with fast-food retail outlets and grocery supermarkets in the selling of their products. Despite the presence of production and marketing contracts, there is also a dynamic interaction between broiler integrators and buyers that is supported by actively traded auction markets for various broiler cuts. More detailed information on the structure and performance of the U.S. broiler industry is provided in other studies (see Goodhue; H.L. Goodwin; Knoeber and Thurman; Tsoulouhas and Vukina). Given the complex interactions between broiler integrators, growers, and marketing-chain stores, it is important to investigate the extent of spatial market integration in this industry. Findings from such study could provide useful information to broiler industry analysts and participants.

The objective of this article is to examine the spatial price dynamics in U.S. regional broiler markets. Specifically, this study analyzes the extent of market integration and investigates whether the law of one price (LOP) holds across the regions. This research extends the literature on spatial price dynamics and makes important contributions in two key ways. First, with an investigation of U.S. regional broiler markets, it fills a gap neglected in the literature on spatial price dynamics for agricultural commodities, which exists despite changes in market structure in the industry that could potentially lead to violations of the LOP. Second, a vector error-correction modeling approach complemented by Granger causality analysis is used to examine the dynamic interactions between four U.S. regional broiler markets: southern, western, northeastern, and midwestern. This modeling approach allows for the analysis of both short-run dynamics and long-run relationships.

Econometric Methodology

Takayama and Judge outlined the theoretical model of spatial competitive equilibrium, which is a basis for the analysis of spatial market integration. If there is physical flow of goods (trade) between two markets, then commodity arbitrage activities by profit-seeking economic agents are expected to force market prices to a unique equilibrium where price differentials are equal to interregional transportation cost. This concept is captured by the LOP. Although the integration of spatially dispersed markets is an indication of the tradability of commodities between markets, it does not necessarily imply that markets are perfectly competitive. The concept of spatial arbitrage and market integration also applies to imperfectly competitive market practices such as basing point pricing (Barrett and Li; Faminow and Benson). Although transportation cost is important to market integration, most studies of spatial price dynamics assume that it is a fixed cost that is implicitly reflected in market prices. A practical reason for the absence of transportation cost is the difficulty in obtaining accurate data on transportation cost. Fackler and Goodwin provide further details on the role of transportation cost for market integration analysis.

Multivariate Cointegration Analysis

Empirical tests of market integration usually investigate the extent to which price shocks in one location are transmitted among spatially separated markets. Early analysis of market integration and the LOP often examine variations of models of price relationships where fluctuations in one market are transmitted to the second market. This equilibrium commodity price relationship can be expressed as follows:

$$(1) \quad P_{1t} = \alpha + \beta_1 P_{2t} + \beta_2 T_t + e_t,$$

where P_{jt} denotes price in market j, T_t denotes transactions costs, and e_t denotes the residuals. The strict version of the LOP is assumed to hold if $\beta_1 = 1$ and $\alpha = \beta_2 = 0$. Similarly, the weak version of the LOP is satisfied if $\beta_1 = 1$ and $\alpha \neq 0$, $\beta_2 \neq 0$. The weak version of the LOP is more commonly observed in the real world. Variations of Equation (1) are often estimated using bivariate static regression models in first differences or in logarithmic form (Fackler and Goodwin). However, this approach has been criticized as inappropriate for capturing the dynamic long-run relationships among commodity prices when the price time series are nonstationary. In such a case, the cointegration modeling technique is the more appropriate estimation method because it can be used to test for the weak version of the LOP.

Recent analysis of the LOP have adopted dynamic time-series techniques, such as Granger causality and cointegrated vector autoregression (VAR) analysis (Bessler and Fuller; B.K. Goodwin and Schroeder; Mohanty, Meyers, and Smith). Similar to previous studies of spatial market integration, this study uses cointegration and error-correction modeling techniques to investigate the spatial relationships in U.S. regional broiler markets. Cointegration tests are particularly useful in the analysis of market integration because cointegration implies the existence of a linear long-run relationship between otherwise nonstationary variables (e.g., regional broiler prices). To satisfy the weak version of the LOP in the context of cointegration analysis, $N - 1$ cointegrating vectors should exist for a set of N spatially separated market prices (B.K. Goodwin). Thus, for the case of four regional broiler-market prices, the LOP could only be supported if there are three cointegrating vectors. However, it is still possible to find a long-run relationship (market integration) without satisfying the LOP. This would be the case if we find less than $N - 1$ cointegrating vectors in a system of N market prices. Such a result would provide evidence of long-run market integration and the existence of some imperfections in the market. This article adopts the Johansen multivariate cointegration-modeling approach to examine the extent of U.S. regional broiler market linkages.

For a given vector of historical price time series P_t, a VAR model can be expressed as

$$(2) \quad \mathrm{P}_t = \mu + \sum_{i=1}^{k} \beta_i \mathrm{P}_{t-k} + \upsilon_t,$$

where P_t is an $(n \times 1)$ column vector of n variables (prices), μ is an $(n \times 1)$ vector of constant terms, β represent coefficient matrices, k denotes the lag length, and υ_t is p-dimensional Gaussian error with mean zero and variance matrix Λ (white-noise disturbance term). Assuming that the vector of variables P_t in Equation (2) is stationary (mean-reverting), then standard ordinary least-squares (OLS) technique can be used to estimate the model parameters. However, most economic time series tend to be nonstationary, and in such cases, OLS is not appropriate.

Cointegration exists if the price series, which are individually nonstationary before differencing, have linear combinations that are stationary without differencing. Johansen and Juselius modeled time series as reduced-rank regression based on maximum likelihood estimation. The multivariate cointegration test is based on the error-correction model (ECM) representation of Equation (2) and is expressed as

$$(3)\quad \Delta P_t = \mu + \sum_{i=1}^{p-1} \Gamma_i \Delta P_{t-i} + \Pi P_{t-1} + \varepsilon_t,$$

where P_t is an $(n \times 1)$ column vector of m variables (broiler prices), μ is an $(n \times 1)$ vector of constant terms, Γ and Π represent coefficient matrices, Δ is a difference operator, k denotes the lag length, and ε_t is independently and identically distributed (i.i.d.) p-dimensional Gaussian error with mean zero and variance matrix Λ (white-noise disturbance term). The coefficient matrix Π is known as the impact matrix, and it contains information about the long-run relationships. If the rank of Π is a positive number r and is less than p, there exist matrices α and β with dimensions $p \times r$, such that $\Pi = \alpha\beta'$. The matrix α measures the strength of the cointegrating vectors and captures the short-run adjustments to long-run relationships. In contrast, the matrix β denotes the number of cointegrating vectors in the ECM. In the latter case, the linear combination represented by $\beta' P_t$ is stationary, even though P_t is not.

Johansen's methodology requires the estimation of the vector error-correction model (VECM) in Equation (3), and the resulting residuals are then used to compute a likelihood ratio (LR) test statistic that can be used in the determination of the cointegrating vectors of P_t. The first test, which considers the hypothesis that the rank of Π is less than or equal to r cointegrating vectors, is given by the trace test below:

$$(4)\quad Trace = -T \sum_{i=r+1}^{n} \ln(1-\lambda_i).$$

The second test statistic below is known as the maximal eigenvalue test, and it computes the null hypothesis that there are exactly r cointegrating vectors in P_t:

$$(5)\quad \lambda_{\max} = -T \ln(1-\lambda_r).$$

The distribution for these tests is not given by the usual chi-square distributions. The asymptotic critical values for the two likelihood-ratio tests are calculated via numerical simulations (Osterwald-Lenum). The null hypothesis is rejected when the estimated likelihood-ratio test statistic exceeds the critical value. Because each of the two tests have their strengths and limitations, it is preferable to make inference using both tests (Cheung and Lai, p. 326).

Assuming nonstationary broiler prices, we can examine the long-run relationships between the markets by determining the number of cointegrating vectors r. Also, short-run integration and the direction of Granger causal flows between markets can be investigated by performing hypothesis tests on the parameters of the VECM. Thus, information about both short-run and long-run market integration could be obtained from the analysis of the VECM in Equation (3).

Empirical Analysis and Results

Data and Integration Properties

To analyze spatial market integration patterns, price data from different regions were necessary. The Bureau of Labor Statistics (BLS) collects this information using a four-region system: Northeast urban (NEAST), South urban (SOUTH), Midwest urban (MWEST), and West urban (WEST).[1] This

[1] The Northeast region consists of Connecticut, Maine, Massachusetts, New Hampshire, New York, New Jersey, Pennsylvania, Rhode Island, and Vermont. The Midwest region consists of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. The South region consists of Alabama, Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, West Virginia, and the District of Columbia. The West region consists of Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

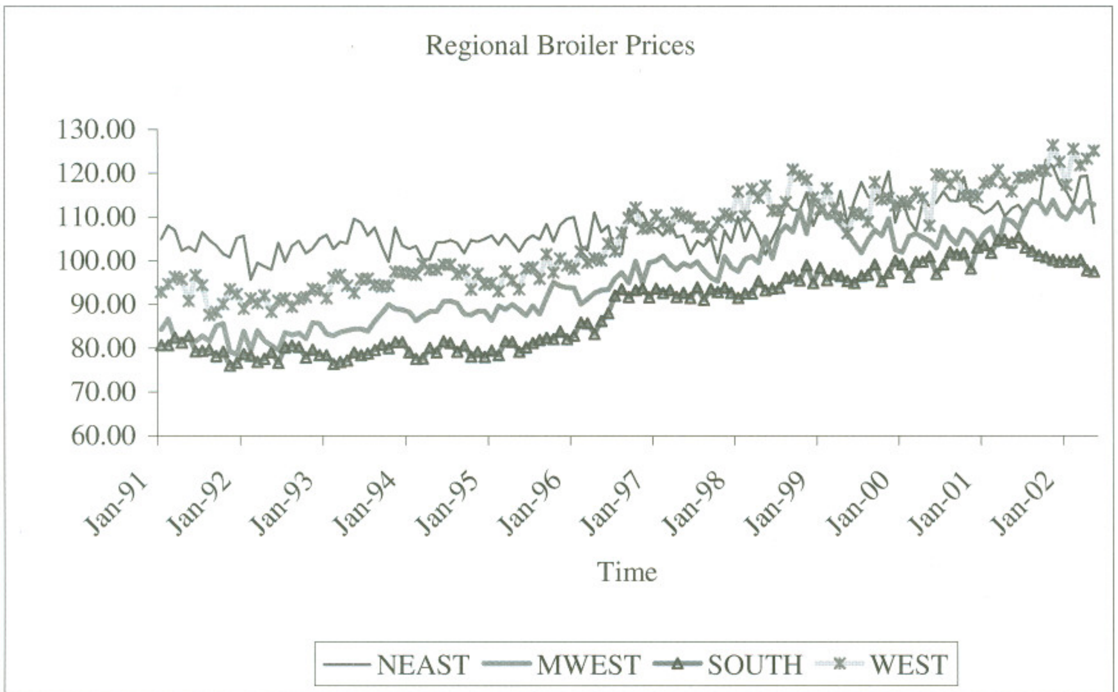

Figure 1. Plot of U.S. Regional Broiler Price Series, 1991–2002

grouping places the vast number of approximately 87% of broilers produced in the SOUTH, followed by the MWEST at 4.7%, the WEST at 3.5%, and finally the NEAST at only 1.7% (USDA/NASS). In terms of ability to meet demand within regions, the NEAST faces the greatest deficit.

The data used in the analysis are the natural logarithms of nominal monthly retail price series for whole, fresh chicken covering the period from June 1991 through May 2002 selected from the consumer price index average-price data provided by the BLS.[2] The use of whole bird prices creates a possible limitation on the extent of the results because they have been a declining portion of broiler sales, representing only 9.5% the last year of the sample (National Chicken Council). However, regional prices for cut-up broilers, 42.5% of the market, were not available for the time period. It is reasonable to assume that spatial price relationships for whole birds would remain a good indicator for the retail broiler market overall given the data constraints. The raw price series, depicted in Figure 1, show considerable fluctuations in the data and suggests the existence of sustained comovements among the variables. Multivariate cointegration tests can provide information on the strength of spatial price linkages and the nature of market performance.

The Johansen cointegration test requires that all variables in the system are stationary after first-differencing (i.e., $I(1)$) before testing for cointegration. Thus, it is important to explore the univariate time-series properties of the data before performing cointegration tests. Two-unit root tests were applied to the price series: augmented Dickey and Fuller (ADF) test and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) Lagrange Multiplier (LM) tests. The ADF procedure tests for the null hypothesis of nonstationarity, but the KPSS procedure tests for the null hypothesis of stationarity. The combination of the ADF and KPSS

[2] Using broiler retail prices does limit the extent to which the results can be generalized to the entire industry because other large segments, such as food-service sales of chicken, are not represented. The increasing importance of food-service sales is beyond the scope of this research, but an interesting area to consider in future analysis.

tests is a form of confirmatory analysis that has been shown to be more robust in determining the presence of unit root (Kwiatkowski et al., p. 176). The unit root tests were conducted for cases with and without linear trends. As shown in Table 1, results from both stationarity tests confirm the presence of unit root. However, no unit root was found when the tests were repeated for the variables in first differences. Thus, all variables are $I(1)$.

Cointegration Test Results

Because the data series are nonstationary in levels, it is possible that cointegration exists between two or more regional broiler price series. Table 2 presents the results from Johansen's multivariate cointegration trace and maximal eigenvalue tests (with and without linear trend in the cointegrating vector space). The chosen optimal lag length of three was based on the Akaike information and the likelihood-ratio criteria. Following Johansen and Juselius, a sequential testing procedure was used. We begin from the topmost row by first testing for zero cointegrating vectors ($r = 0$) assuming there is a constant in the cointegrating space. If this hypothesis is rejected, then we test for $r = 0$ assuming that the constant is *not* in the cointegrating space. If this hypothesis is rejected, we next test for $r \leq 1$ with constant in the cointegrating space. This sequential testing process continues until the first time we fail to reject the null hypothesis.

As shown in Table 2, both trace and maximal eigenvalue test statistics yield identical conclusions indicating the presence of a single cointegrating vector (and three stochastic trends) among the four broiler-market prices. The existence of a cointegration relationship implies that there is long-run market integration between these four regional broiler markets. However, the finding of only one cointegrating vector suggests that the regional broiler prices are not pairwise cointegrated. This result implies that although we find empirical evidence that the four regional broiler markets are spatially integrated in the long run, the LOP does not hold (Ghosh; B.K. Goodwin). To an extent, this result might suggest the presence of some form of market imperfection in the broiler industry. In a vertically integrated broiler industry, this finding may reflect the possible coordination of prices by the integrator firms. It is plausible to assume some degree of price coordination across markets because many integrators have chicken growers across the nation that cater specifically to broiler demand in geographically dispersed markets. In such a case, the spatial price linkages cannot be fully attributed to allocative efficiency due to market arbitrage activities.

Granger Causality Test Results

Table 3 reports the result for the Granger causality test for short-run integration using the VECM specification in Equation (3). The Granger causality test results suggest that the direction of causal flow of price information in the broiler markets is from the major supply regions to the high-demand regions. There is no statistically significant feedback causal flow from net-importer to net-exporter regions.

Table 1. Augmented Dickey-Fuller (ADF) and KPSS Tests for Unit Roots

	Levels		First Differences	
Prices	ADF	KPSS	ADF	KPSS
NEAST	−2.15	1.21*	−9.54*	0.16
MWEST	−0.63	1.38*	−12.22*	0.18
SOUTH	−0.63	1.34*	−17.31*	0.11
WEST	−0.22	1.37*	−9.81*	0.13

* Null hypothesis for ADF test is nonstationarity, whereas the KPSS tests for stationarity. The choice of optimal lags for ADF test was based on the Akaike Information Criterion. Critical values for the ADF tests are −2.86 (without trend) and −3.41 (with trend) at the 5% level. Critical values for the KPSS tests are 0.463 (without trend) and 0.146 (with trend) at the 5% level.

Table 2. Multivariate Cointegration Tests of Spatial Market Integration

Null Hypothesis	Eigenvalue	Trace Statistic	C(5%)	λ-Max Statistic	C(5%)
Constant in the Cointegrating Vector					
$r = 0$	0.22	62.67*	53.12	33.17	28.14
$r \leq 1$	0.11	29.50	34.91	15.59	22.00
$r \leq 2$	0.08	13.91	19.96	11.38	15.67
$r \leq 3$	0.02	2.53	9.24	2.53	9.24
Constant Outside the Cointegrating Vector					
$r = 0$	0.22	57.72*	47.21	33.09	27.07
$r \leq 1$	0.11	24.63	29.68	15.45	20.97
$r \leq 2$	0.07	9.19	15.41	9.06	14.07
$r \leq 3$	0.00	0.13	3.76	0.13	3.76

* Indicates rejection of the null hypothesis at the 5% significance level. C (5%) are critical values obtained from Osterwald-Lenum. The number of cointegrating vector is the point where we first fail to reject the null.

Specifically, regional broiler prices in the SOUTH and WEST regions are not affected by changes in the other two markets. In contrast, the fluctuations in broiler prices in the SOUTH region significantly influence prices in the NEAST and MWEST markets at the 5% significance level.

It is important to note that the SOUTH is by far the largest production region, and the level of broiler production in the WEST is relatively much smaller. Thus, the result of a causal flow of price information from the west to the northeast needs to be viewed with caution. The West is not competitive with the South in its ability to supply lower cost broilers to the Northeast market. Thus, the link between price shocks in the West and Northeast prices could be seen more as a secondary phenomenon that may not necessarily reflect trade patterns. Rather, this may represent an indirect effect of price coordination by integrators. For example, an integrator firm with operations in both the South and the West could coordinate prices in both regions. Thus, price shocks in either market could have similar effect on Northeast broiler prices.

As previously noted, NEAST broiler prices are significantly influenced by changes to broiler prices in the WEST region. The response of the NEAST market to price shocks in both the SOUTH and the WEST regions indicates that this region is relatively more responsive to outside price signals. This finding confirms prior expectation that the wholesale market demand for broilers in the densely populated NEAST region depends on imports from other production regions to satisfy high local demand for broiler meat. The finding of a unidirectional Granger causality from the SOUTH market price to the NEAST and MWEST market prices seems to suggest that the SOUTH region is relatively dominant in terms of its influence on the

Table 3. Causality Test Results Based on VECM

Dep. Variables	*F*-Statistics NEAST	MWEST	SOUTH	WEST
NEAST		2.83 (0.24)	7.33 (0.03) *	14.06 (0.00)
MWEST	0.31 (0.86)		7.02 (0.03) *	2.11 (0.35)
SOUTH	1.51 (0.47)	5.53 (0.06)		0.34 (0.84)
WEST	1.21 (0.55)	1.27 (0.53)	0.06 (0.97)	

* Indicates statistical significance at the 5% level. Reported estimates are *F*-statistics and the p-values are in parentheses.

determination of broiler market prices in other regions. It is also notable that although the MWEST responds primarily to price signals from the SOUTH, the NEAST market responds to price signals from both the SOUTH and WEST broiler markets. This may be reflecting the fact that the MWEST region has a relatively smaller market demand for broilers than the more densely populated NEAST regional market.

Concluding Remarks

In the past few decades, U.S. broiler production has become the most vertically integrated industry in U.S. agriculture, and the trend toward higher firms and geographic concentration of this sector has been rapid and quite dramatic (H.L. Goodwin). A relevant empirical question is how the recent changes in the broiler-industry structure have affected the transmission of price information in the market. This article focused on the analysis of spatial price relationships among four U.S. regional broiler markets. Specifically, the extent of long-run and short-run market integration was investigated via the analysis of dynamic time-series models (Cointegration and Granger causality models). The U.S. national broiler market was divided into four main regions: West urban (WEST), South urban (SOUTH), Northeast urban (NEAST), and Midwest urban (MWEST).

Empirical results provide two significant findings about the spatial behavior of U.S. broiler prices. First, the results from the Johansen multivariate cointegration test suggest the existence of one cointegrating vector in the four-variable system indicating that long-run integration exists among these four regional broiler markets. However, the law of one price (LOP) is not supported as we do not have the case of pairwise cointegration. This is an important finding because of its implication for market structure. If the broiler market operates under perfect competition, there should have been at least three cointegrating vectors in a four-variable system. The current finding of a single cointegrating vector thus implies the presence of some degree of market imperfection in the U.S. broiler industry. This evidence in support of imperfect competition is consistent with conventional wisdom for an industry that is highly vertically integrated and increasingly more concentrated.

Another significant finding of this study is that short-run causal flow of price signals is from the net-producing regions to the net-consuming regions. Granger causality flows from the SOUTH regional prices to the NEAST and MWEST regional broiler markets. The NEAST market also responds to price signals from the WEST regional market. The SOUTH and WEST (to a lesser degree) appear to be dominant as the other regional broiler markets respond to fluctuations in these markets' prices. Overall, the findings from this study show that there is significant long-run market linkage among U.S. regional broiler prices. In addition, these results show that regions with a high concentration of integrators have significant influence on prices in nonproduction intensive regions. The empirical results from this study are consistent with the recent trend of higher concentration and vertical integration in the broiler industry.

Perhaps the main limitations of the study revolve around the data. As noted in Bernard and Willett, although important results can be discovered through examining whole bird prices, their falling share of the retail broiler market relative to broiler parts can leave some questions. The reporting of regional prices for the latter would be necessary to expand on this analysis. Beyond that, concern would be the growing proportion sold as further processed products. The spatial price relationships for these products, mostly branded and differentiated, would likely be much different and considered a separate area for research. Another avenue of future analysis would be to examine price relationships in the food-service segment of the market. With that segment representing about 42% of the market, any concerns over market performance would be of interest in that venue as well.

Although several previous studies have investigated the spatial price dynamic relationships among several U.S. agricultural prices (e.g., grain and livestock markets), surprisingly, no previous study had specifically investigated the nature of market integration for regional broiler markets. Thus, this study makes an important contribution in providing useful empirical evidence on the nature of the spatial price dynamics in the U.S. broiler industry. Furthermore, although the existence of cointegration among these regional market prices suggests that increased concentration and vertical coordination may be linked to increased price coordination, it does not provide strong empirical justification for extensive government intervention in the broiler markets.

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