Beef Safety Shocks and Dynamics of Vertical Price Adjustment: The Case of BSE Discovery in the U.S. Beef Sector

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ABSTRACT

This article addresses the dynamic impact of the 2003 *Bovine Spongiform Encephalopathy* discovery on the U.S. beef sector. Time series analysis and historical decomposition with weekly feedlot, wholesale, and retail beef price series is used to address the dynamics of price adjustment and causality along the U.S. beef marketing channel. The results show price transmission is bidirectional, determined through interaction between the different stages, and price adjustment is asymmetric with respect to both speed and magnitude. The results reveal a differential impact of the exogenous shock on producers and retailers, which leads to widening of price margins and points to imperfect price transmission, specifically at the retail level, with consequences for the efficiency and equity of the marketing channel. [EconLit citations: Q11, Q13]. © 2007 Wiley Periodicals, Inc.

1. INTRODUCTION

Over the past twenty years highly publicized incidents of beef safety scares such as E. coli food poisoning, foot and mouth disease (FMD) outbreaks, and Bovine Spongiform Encephalopathy (BSE) discovery have been reported worldwide. The impact of such events on consumers' meat demand has received the bulk of the attention in the literature, in part due to human health and safety concerns. An additional important issue is how food safety shocks and their related consumer reactions impact price adjustments across vertically linked markets.

BSE is a fatal neurological disease that can occur in adult animals aged five years or older. The exact cause of BSE is not known, but it is primarily transmitted by the feeding of diseased animal products. Consumption of contaminated beef by humans is suspected to cause Creutzfeldt-Jakob disease. Quickly after the BSE discovery in the U.S. in December 2003, USDA announced additional beef safety procedures by banning specified risk material (SRM) such as brain, spinal tissue, etc., of cattle over 30 months of age from food supply to ensure the safety of U.S. beef. The list of SRM in the U.S. is consistent with the SRMs specified by Canada following of its first domestic case of BSE.

While BSE discovery in other countries such as the United Kingdom and Japan resulted in considerable economic damage to beef producers as well as food service industries, the notable impact in the U.S was mostly on the export sector; Japan, a major export market for U.S. beef and beef products stopped all imports. In this research, we investigate the

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impact of the BSE discovery on the U.S. beef sector by focusing on the short-run dynamics of price adjustment and price transmission along the U.S. beef marketing channel to see whether the beef safety scare affected the price margins along the supply channel.

Research on vertical and spatial price transmission is vast, expanding in different directions from asymmetric price transmission, price stickiness, and incomplete price pass through to market efficiency, integration, concentration, and power. Considering the fact that, in recent years, the U.S. beef industry has faced notable structural changes and higher market concentration, an important research question is to what extent the BSE shock in the U.S. beef sector was transmitted through the supply chain and impacted prices at feedlot, packer, and retail levels. Market concentration and the likely presence of market power can potentially influence the degree and dynamics of price transmission, leading to differential price effects on different stages of the chain. Differing market operation dynamics under competitive and noncompetitive market conditions can also have welfare implications with respect to the efficiency and equity of the marketing system.

The literature on impacts of food safety scares includes a wide range of theoretical and empirical demand models from the Almost Ideal Demand System and Rotterdam models and their different variations to experimental auction models, contingent valuation, and conjoint analysis. These models, however, are inappropriate to investigate the short-run dynamics of price adjustment, which are due to unanticipated exogenous food safety shocks. This study employs a vector error correction (VEC) model along with directed acyclic graphs and historical decomposition to investigate the dynamics of price transmission along the U.S. beef supply chain.

The VEC model will not only allow estimates of short-run speed of adjustment for the price series but also preserve the long-run relationships among the variables. Cointegration is used as a tool to evaluate market efficiency and can analyze both perfect and imperfect market conditions. Cointegration of prices in distinct markets is an indication of price transmission and market integration. Its convergence property is consistent with the hypothesis that arbitrage binds prices into a long-run relationship. It is now commonplace to test the extent of price transmission through the chain by cointegration techniques.

Historical decomposition traces the short-run dynamic effects of the beef market shock on prices and aids in providing a visual explanation of the impact of the BSE scare on the price series in the neighborhood of the event. Specifically, orthogonal innovations are constructed using graph theory to determine causal patterns behind the correlation in contemporaneous innovations of the structural VEC model. Historical decomposition is usually applied to macroeconomic shocks. To our knowledge, only Chopra and Bessler (2005) have applied historical decomposition to agricultural prices; they were investigating price reactions in the neighborhood of a food safety event examining short and long-run BSE and FMD impacts in the United Kingdom.

The Literature Review section provides a review of the literature. Following that, the Data, Econometric Model Development, and Empirical Results section presents information about the empirical model employed, the data used, and the empirical results of this research, followed by a discussion and concluding remarks in the Summary and Conclusions section.

2. LITERATURE REVIEW

There are a great number of research articles on market integration and price transmission along the agricultural marketing channels and the factors that influence price spreads between different stages of the channel from farm to wholesale and retail. The overall concern is whether pricing patterns are cost or demand driven. While prices can be transmitted temporally, vertically, or spatially, the early literature in this area typically focused on farm-retail spreads in agricultural markets to analyze rapid producer price changes and how they were passed to consumers, also addressing expenditure shares spent on meat as a percentage of overall households' food expenditure shares. The early models utilized were primarily static linear equilibrium models, applied to perfectly competitive markets. An important example of this literature is the work of Gardner (1975). He used a generalized proportion model to investigate the factors that influence the price of marketing services and price transmission between farm and retail sectors, focusing on the source of the exogenous shock on supply and demand functions, i.e., whether the shock occurs on the retail or the supply side.

Market integration and price transmission theory has evolved extensively since Gardner's seminal work in important ways, expanding the literature in different directions to address issues such as dynamics of price transmission, causality, short- and long-run price adjustment differentials, asymmetric price adjustment, and market efficiency and power. In general, using conventional linear models in a nonlinear situation leads to the wrong conclusions, and static models are incapable of addressing such issues as short- and long-run variability and speed of price adjustment. Heien (1980) added dynamic analysis to address short-run disequilibrium price adjustments. Jumah (2004) explained that dynamic model specification would be more appropriate when all variables are changing intertemporally and also when dealing with conjectural variation and rivalry in oligopolies where a change in one firm's decision can lead to quick reactions by rivals.

The causality issue refers to the direction of price movements along the supply chain. According to price determination theory, producer price changes determine retail price changes; that is, price transmission flows downward along the supply chain and the direction of causality runs from producer to retail prices. However, the empirical results of studies applied to different commodities in different countries regarding this issue are mixed. For example, Tiffin and Dawson (2000), studying the UK lamb market, found that lamb prices were determined in the retail market and then passed upward along the supply chain; that is, the direction of causality is from retail to producer prices. Goodwin and Harper (2000) and Goodwin and Holt (1999) found that retail market shocks were confined in retail markets for the most part, but farm markets adjusted to shocks in wholesale markets. However, Ben-Kaabia, Gill, and Boshnjaku (2002) found both supply and demand shocks were fully passed through the marketing channel, i.e., they found complete price transmission.

Many researchers have addressed the issue of price stickiness and incomplete price transmission, providing a detailed explanation for asymmetric price behavior. While short-run price behavior is better understood and explained, the longer term movements of margins is not fully understood (Tiffin and Dawson, 2000); short-term disequilibria usually vanish in the long-run. Price transmission can be asymmetric when the speed of price adjustment across vertically linked markets is different. Price asymmetry can exist with respect to magnitude or speed or a combination of the two. In the case of magnitude, long-run elasticities of price transmission differ depending on the direction of the initial price change; in the case of speed, short-term elasticities are different (Luoma, Luoto, & Taipale, 2004).

It is important to note that there are different definitions of price asymmetry. In this research, the focus is on the different speeds of price adjustment along the beef marketing channel in the feedlot, wholesale and retail markets affecting price margins. The traditional definition of price asymmetry, which also affects price margins, refers to a situation where increases in producer price are moved faster and more completely to consumers than price reductions (Bakucs & Ferto, 2005; Pelzman, 2000). It is important to note that in those cases the standard Dicky-Fuller unit root tests used in this study are misspecified and are not efficient in detecting cointegration relationship (Enders & Granger, 1998)[1].

The analysis of vertical price relationships is a useful tool in evaluating the degree of competition and the efficiency and equity of the marketing system in agricultural markets. There are many notable developments of price transmission theory in the area of market efficiency and imperfect competition (e.g., Azzam & Pagoulatos, 1990; Holloway, 1991; Hyde & Perloff, 1997, among others). In an efficient market, condition prices are transmitted fully and completely. The fact that price dynamics may differ under competitive and noncompetitive market conditions can lead to market inefficiency. In a study, McCorriston et al. (1998) demonstrated the role of oligopoly power in determining the price transmission elasticity following a supply shock. Other studies have supported the hypothesis that market concentration and imperfect competition can be the cause of asymmetric price transmission (Lloyd, McCorriston, Morgan, & Rayner, 2003; Miller & Hayenga, 2001).

Luoma, et al. (2004) has also argued that market power is the most likely explanation for asymmetric price transmission in the long run. In imperfectly competitive markets, retailers may keep price levels relatively fixed for long periods, or oligopolies may react quicker to declining margins by utilizing their market power. The reason they do this is to maintain market shares, keeping long-run rather than short-run profits in mind. Hence, market power can affect price transmission in opposite ways (Jumah, 2004). Also, Lloyd et al. (2003), who investigated the impact of the BSE scare in the UK meat market, also tested the hypothesis that market power could cause the margin between retail and farm prices to widen. Those results have clear consequences for this study and may be an explanation for the results of this research, considering the fact that the U.S. beef industry is now faced with notable wholesale and retail market concentration.

3. DATA, ECONOMETRIC MODEL DEVELOPMENT, AND EMPIRICAL RESULTS

The Livestock Marketing Information Center (LMIC) weekly time series beef price spreads were assembled for the period from January 5, 1991 to July 2, 2005 for feedlot prices $\{P_{ft}\}$, wholesale prices $\{P_{wt}\}$, and retail prices $\{P_{rt}\}$. The vertical structure of the data set begins with feeder cattle followed by live cattle, wholesale, and retail levels. All prices are in dollar per hundred weights (\$/cwt). The feedlot price used in this analysis is the Kansas live cattle price databased by the LMIC. A 1000 lb steer is assumed and multiplied by this Kansas price to derive a live steer value. The total wholesale value is the sum of the boxed beef value and the byproduct value. Both are USDA prices, again databased by the LMIC. From assumed 1000 lb steer, a dressing percentage of 63% and a retail yield of 42.7% from the live animal weight are estimated. The retail value is the monthly USDA reported retail price multiplied by the estimated retail yield. Descriptive statistics of the price series are provided in Table 1.

[1]We are indebted to an anonymous reviewer for this insight.

TABLE 1. Descriptive Statistics of Continuous Variables[a]

	Feedlot	Wholesale	Retail
Mean	719.57	830.79	1424.58
Median	702.11	807.35	1323.64
Maximum	1066.80	1333.73	1957.93
Minimum	554.00	679.26	1244.82
Std. Dev.	84.95	98.51	189.21
Skewness	0.84	1.40	1.38
Kurtosis	3.59	5.50	3.64
Observations	757	757	757

[a]Calculations are based on weekly observations of prices in $/cwt for the period 1/5/1991 to 7/2/2005.

These beef prices are for all beef grade average. The assumption is that the BSE discovery reported by the news outlets affects quality perception of all beef, consistent with other research in this area (e.g., Piggott & Marsh, 2004). While the beginning date of the BSE scare is well known, there is no way to know exactly how long the impact of the beef safety scare on consumers' perception of beef safety can last. In this research we concentrate on the short-run dynamics of price adjustment and price transmission at different market levels in a neighborhood around the BSE shock specified by the historical decomposition graphs, though price transmission patterns could be different before and after the BSE scare.

Sociological researchers argue that, generally, a food safety scare can have short-run and long-run effects depending on the source and type of contamination as well as the extent of the media attention. If the contamination receives prominent media coverage, consumers may initially overreact by avoiding the identified food item, but concerns gradually diminish and consumers revert back to old consumption habits, though low-level anxiety can continue for some time (Mazzocchi, 2005).

Given the nature of the underlying data series, we closely follow the contemporary nonstationary time series modeling paradigm. First, the temporal properties of the three price series are analyzed using augmented Dickey-Fuller tests. The tests involve running a regression of the first difference of each series against the series lagged one period, lag difference terms, and a constant. The null hypothesis is that the series are nonstationary in their levels. The nonstationary series are integrated of order one or I(1) with the first differences being stationary or I(0). Second, Johansen's cointegration tests are employed to determine if a long-run relationship exists among the three variables in the system. Whenever the series are integrated and cointegrated, a VEC Model is appropriate to characterize the multivariate relationships among the variables.

Next, we estimate a VEC model and conduct hypothesis testing within this framework. The VEC model uses both short-term dynamics as well as long-term information. Following that, we utilize Granger causality tests and directed acyclic graphs to investigate the causal patterns among the variable. Directed graphs allow the errors among the endogenous variables to be incorporated into the forecasted effects of the beef market shock over time. Finally, historical decomposition of feedlot, wholesale, and retail-level price series aids in explaining the behavior of beef prices due to the BSE shock. This is based on the application of directed acyclic graphs constructing orthogonal innovations to determine causal patterns behind contemporaneous innovations.

TABLE 2. Augmented Dickey-Fuller (ADF) Test Results

Statistic/diagnostic	P_{ft}	P_{wt}	P_{rt}
Test results for variables in levels			
ADF Test[a]	2.41	2.34	0.88
F Test	22.46*	49.96*	0.77
Durbin Watson	1.98	2.01	1.98
Test results after first-differencing variables			
ADF Test[a]	23.42*	16.32*	9.50*
F Test	338.69*	226.67*	155.03*
Durbin Watson	1.98	2.00	2.00

*1% significance level.
[a]In absolute value and compared to MacKinnon (1996) critical values.

Previous research indicates these series are likely to be nonstationary. Consistent with the literature, we use an augmented Dickey-Fuller (ADF) test to determine the order of integration of each price series. For example, in the retail price series $\{P_{rt}\}$, the usual ADF test statistic is obtained from the parameter in the regression model $\Delta P_{rt} = \alpha_0 + \alpha_1 P_{rt-1} + \sum_{j=1}^{n} \beta_j \Delta P_{rt-j} + \upsilon_t$, where H_0: $\alpha_1 = 0$ is tested against H_1: $\alpha_1 < 0$ with P_{rt} representing the natural logarithm of observed retail prices.

Following Enders (1995) and Hendry's (1986) "General to Specific" procedure, we started with an over-specified ADF regression where *n*, the number of lags, was relatively large and then employed a battery of lag length diagnostic tests to refine the specification for each univariate series to reach $n = 4$. The upper portion of Table 2 summarizes the ADF test results for each variable, while the lower portion catalogues the results for the first difference of each price series. Given a MacKinnon 10% critical value, we failed to reject the null hypothesis of a unit root for these variables with two terms, a constant and a trend. Each series was then first differenced and the ADF regressions were reestimated with a constant but no trend. In each case, we rejected the null hypothesis of a unit root at the 1% level of significance. These stationarity tests are the same as checking the series for the order of integration to see if their mean and variance change and are not constant over time. When the series are integrated of order one, the series then will be checked for long-run equilibrium or cointegration.

3.1 Johansen's Cointegration Tests

Following Enders (1995), when the series are I(1) processes, the possibility of equilibrium is examined using Johansen's cointegration test.[2] These results are reported in Table 3. Johansen's test is a likelihood ratio (LR) test designed to determine the number of cointegrating vectors in the system or the cointegrating rank *r*. Theoretically, the rank *r* can be at most one less than the number of endogenous variables in the model. The LR test in our analysis determines if two cointegrating vectors exist between the three endogenous price series.

We follow Johansen's testing procedures to specify a cointegration model consistent with the underlying data generation process. Each cointegrating equation contains an

[2]We used the Eviews (2004) software package.

TABLE 3. Johansen Cointegration Test Results

Null hypothesis[a]	Trace statistics	5% Critical value	Eigenvalue
$r = 0$*	80.56	29.80	0.08
$r \leq 1$*	17.63	15.49	0.02
$r \leq 2$	2.03E-05	3.81	0.051

[a]r is the cointegrating rank.
*Denotes rejection of the hypothesis at the 5% level.

intercept and a slope coefficient. At the 5% level of significance for the trace test (Johansen & Juselius, 1992), we reject the null hypotheses that $r = 0$ and $r \leq 1$, but we failed to reject the null hypothesis that the cointegrating rank of the system is at most two at the 5% level. These results suggest there are two long-run equilibrium relationships between the three price series. The cointegrating vectors provide the foundation to empirically address short-run economic reactions and the speed of adjustments, trends, and long-run equilibria.

3.2 Vector Error Correction Model

A more contemporary approach to quantifying the relationship between I(1) series is to construct a VEC model. The ADF test results suggest that a VEC model is more appropriate than a vector autoregression model (VAR) to characterize the multivariate relationships among the three price series (Engle & Granger, 1987). A VEC is a VAR in first-difference form that explicitly incorporates cointegration to capture the information contained in each series' long-run stochastic trend, and reflects the fact that the variables are I(1) and must be differenced.

In this model,

$$\Delta P_t = \alpha_0 + \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \Pi P_{t-k} + \varepsilon_t$$

the first difference of each price series is represented as a function of its own lagged values, the lagged values of the other variables, and cointegrating equations. The specification of the VEC model used to conduct the analysis is as follows: where ΔP_t is a (3×1) matrix (ΔP_{1t}, ΔP_{2t} and ΔP_{3t} represent the three price series); α_0 is a (3×1) vector of intercept terms; the $\Gamma_i \Delta P_{t-i}$ terms reflect the short-run relationships among elements of the P_t matrix; and the Π matrix captures the long-run relationship among the variables. The Π matrix can be decomposed into two $p \times r$ matrices, α and β, where $\Pi = \alpha\beta'$. The matrix β contains the cointegrating vectors that represent the underlying long-run relationship and the α matrix describes the speed of adjustment at which each variable moves back to its long-run equilibrium after a temporary shock or departure from it (Johansen & Juselius, 1992; Schmidt, 2000).

The stability of the dynamic VEC model is an important issue that needs to be addressed. We have to make sure the dynamic model is stable and the adjustment paths converge to the long-run equilibrium as time passes. The VEC model is stable if all the characteristic

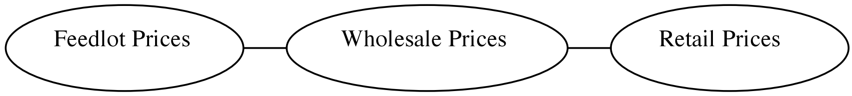

Figure 1 Characteristic roots of the VEC model.

roots have modulus less than one and lie inside the unit circle.[3] Figure 1 shows the dynamic model is stable and all the characteristic roots are within the unit circle.

The lag length testing procedures for the VEC closely parallel those for the ADF tests. Again, we started with an over-specified model where *k* was relatively large and reduced the number of lags until a parsimonious specification was obtained. The diagnostics of the VEC model are summarized in Table 4. The usual loss functions, AIC and Schwarz criterion, were minimized in the neighborhood of four lags. The log likelihood function of the system approached its maximum near the final specification. As expected, we found no evidence of first-order autocorrelation at the 5% level of significance using the Durbin-Watson bounds test. The R^2 values indicate that between 13% to 39% of the variation in the natural logarithms of the price series are explained by the models.

3.3 Dynamic Speeds of Adjustments

The VEC model analysis of dynamic adjustments permits this study to provide a precise measure of the speeds of price transmission. The empirical estimates of the speeds of adjustment are summarized in the top portion of Table 4. The speeds of adjustment for wholesale and retail price series were statistically significant at the 1% level. The speed of adjustment for feedlot prices was not statistically significant. The dynamic speed of adjustment for wholesale prices was much higher (0.13), in absolute value, than retail prices (0.02), an indication of asymmetric price transmission with respect to speed. This is an interesting result suggesting that with the beef safety shock, wholesale prices adjust much more quickly and are more flexible than retail prices to restore the long run equilibrium.

This is an important result for policy makers and agribusinesses and has clear implications for the efficiency and equity of the beef marketing system. These results indicate that the speeds of price adjustment are different in different markets and prices in the wholesale market adjust more than six times faster than prices in the retail market in response to the BSE shock. Because wholesale prices decrease faster than retail prices, the burden of the BSE shock is borne more by the wholesalers than retailers. As a result, the wholesale-retail price margin is widened.

A BSE shock is hypothesized to affect consumers' perception of beef quality negatively and is anticipated to cause spot beef prices to decrease. It also leads to the anticipation of price decreases in the futures market. If we assume a perfect competitive market condition such as an auction market with perfect information and no adjustment costs or explicit contracts, then prices should be flexible and adjust quickly and fully in response to the BSE scare; the shock should induce an immediate decrease in spot prices. However, that is not the case here.

[3]If the model is not stable, results are not valid and long-run steady-state equilibrium does not exist.

TABLE 4. The Empirical Estimates of Speeds of Adjustment and Diagnostics

Variable	ΔP_{ft}	ΔP_{wt}	ΔP_{rt}
Speeds of adjustment	−0.01	−0.13*	−0.02*
Model diagnostics			
R^2	0.14	0.39	0.13
AIC	−4.79	−5.38	−7.17
Schwarz criterion	−4.70	−5.29	−7.08

*1% significance level.

These results might be signal of more concentration and market power in the retail market. In an efficient market condition, prices are transmitted fully and completely. The fact that price dynamics differ point to noncompetitive market conditions that can lead to market inefficiency. Yet, our analysis cannot directly test for imperfect competition and does not address the issue of concentration and market power explicitly. Future research and modeling efforts are required to address this hypothesis appropriately. The results seem to indicate that the wholesale beef market is more competitive and operates more efficiently than the retail market, though there have been concerns regarding the high degree of packer concentration at the wholesale level. If that is proven to be true, then it would refute the hypothesis that higher packer concentration has increased imperfectly competitive behavior at the wholesale.

Economists at the Economic Research Service, U.S. Department of Agriculture (Mathews, Hahn, Nelson, Duewer, & Gustafson, 1999), have found no evidence to support the hypothesis that increased slaughter concentration results in lower farm prices. Also, the results of Goodwin and Holt (1999) do not imply the existence of market power at higher levels of the chain. Karp and Perloff (1993) have also shown that the dynamic behavior of oligopolies is relatively more competitive than collusive. Our result shows the retail beef prices to be relatively more "sticky," drawing attention to concentration and imperfect competition at the retail level. Previous research applied to the Spanish lamb sector has also found increased horizontal concentration allows retailers to exercise market power (Ben-Kaabia et al. 2002).

Some other explanations given in the literature for the causes of price asymmetry are product heterogeneity, long-term contracts, and adjustment or menu costs (e.g., Goodwin & Holt, 1999; Zachariasse & Bunte, 2003), which may explain the differential speeds of price adjustment along the U.S. beef marketing channel. Originally, Hick's (1974) and Okun's (1975) works showed that prices in some sectors of the economy were sticky while prices in other sectors were flexible. According to their arguments, prices of most goods and services are not free to respond to changes in demand in the short run. In this class of goods, which are called fix-price goods by Hicks and customer goods by Okun, prices are sticky in the short run. This is due to imperfect information, costs of changing prices, explicit contracts, etc. Most prices of manufacturers, services, and, in general, heterogeneous good fall under this category.[4] Bordo (1980) who was investigating the

[4]The other goods, which are called flex-price goods by Hicks and auction goods by Okun, are those in which prices are free to respond to changes in demand in the short run. Prices of most commodities that are homogeneous and traded in auction markets adjust instantaneously in response to exogenous shocks and fall under this category.

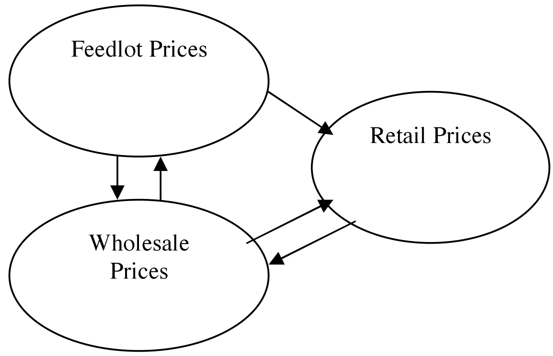

Figure 2 Causal structure on innovations from the beef price series (5% level).

role of long-term contracts and monetary policy on relative commodity prices empirically showed that some prices respond slowly to policy shocks due to long-term contracts.

3.4 Causality and Directed Graph

The covariance matrix of the VEC model is used to investigate the causal relationship among the variables by directed acyclic graphs (Babula, Bessler, & Payne, 2004; Bessler & Akleman, 1998;).[5] An algorithm is utilized which first assigns undirected lines to all the nodes (variables) and then removes adjacent edges when partial correlations are not statistically significant and determines causal flow directions for the remaining edges based on the partial correlations of the residuals (Spirtes, Glymour, & Scheines, 2000). This will allow writing the price vectors in terms of orthogonalized innovations (Swanson & Granger, 1997). The TETRAD IV software (Spirtes et al., 1999) is used to generate the causal patterns among the beef price series. Figure 2 presents the causal structure of the three beef price series on innovations from the three variables generated by the TETRAD software at the 5% significance level. The results show that innovations in feedlot and wholesale and in wholesale and retail price variables affect residuals in each other (i.e., there is a connecting edge), but they are not connected by directed paths; that is, there are no arrows to indicate direction of causality.[6] Also, there exists no residual relationship between feedlot and retail beef prices; the relationship between feedlot and retail beef price residuals is through wholesale prices.

Because directed graph results from the residuals are inconclusive and do not provide a clear causality direction, we employ pairwise Granger causality tests (with four lags) to investigate causal directions.[7] The results are summarized in Table 5. F-test results indicate that the hypothesis, retail prices do not Granger cause feedlot prices, is the only one

[5]A directed graph is a picture representing the causal flow among a set of variables called nodes. Lines with arrowheads are used to represent causal directions so that an arrowhead from node A to node B means variable A causes variable B. A connecting line with no arrowhead indicates the two variables are connected by information flow, but we cannot say which one causes the other.

[6]According to the TETRAD software, this is a case where an edge between A and B indicates that (a) either A is a cause of B or B is a cause of A, or (b) there is a common latent cause of A and B, or (c) there is some combination of these; but, the direction of causality is not known given the nature of residuals at hand.

[7]TETRAD literature indicates that the software usually underestimates.

TABLE 5. The Results of Pairwise Granger Causality Tests

Null hypothesis	F-Statistic
Feedlot price does not granger cause wholesale price	41.94**
Wholesale price does not granger cause feedlot price	7.01**
Wholesale price does not granger cause retail price	17.07**
Retail price does not granger cause wholesale price	4.88*
Feedlot price does not granger cause retail price	12.49**
Retail price does not granger cause feedlot price	1.73

**1% significance level, *5% significance level.

that cannot be rejected. The results show the direction of causality runs especially strong from feedlot to wholesale to retail level. However, this relationship is not unique (i.e., unidirectional); there are causality relationships going upstream, from retail to wholesale to feedlot level, as well.

In contrast to Goodwin and Holt (1999), who found unidirectional price transmission from farm to wholesale to retail, our results reject the hypothesis that price transmission in the U.S. beef sector flows only downward along the supply chain with the direction of causality running from producer to retail prices. These results suggest that prices in the U.S. beef sector are not determined at one end and then passed down or up along the supply channel. That is, pricing patterns in the U.S. beef sector are not just cost or demand driven. Prices are determined simultaneously through bidirectional interaction between the different stages (likely through contracts). These results are summarized in Figure 3.

3.5 Historical Decomposition Graphs

Earlier, we discovered that the speeds of price adjustment along the U.S. beef supply varied in response to the BSE scare. The next important step is that of measuring the magnitude of price transmission due the BSE shock, which can be handled by historical decomposition graphs. Historical decompositions based on causal patterns decompose the price series of the structural VEC model to determine the impact of the safety shock

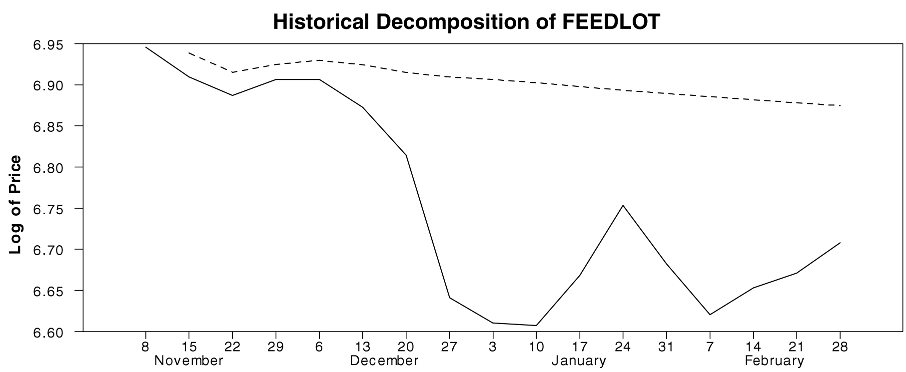

Figure 3 Granger causality results (5% significance level).

on prices in a neighborhood (time interval) of the beef safety scare. Historical decomposition graphs are based upon partitioning of the moving average series into two parts:

$$P_{t+j} = \sum_{s=0}^{j-1} \psi_s U_{t+j-s} + \left[X_{t+j}\beta + \sum_{s=j}^{\infty} \psi_s U_{t+j-s} \right]$$

where P_{t+j} is the multivariate stochastic process, U is its multivariate noise process, and X is the deterministic part of P_{t+j}. The first sum represents that part of P_{t+j} due to innovations (shocks) that drive the joint behavior of beef prices for period $t + 1$ to $t + j$, the horizon of interest, and the second is the forecast of price series based on information available at time t, the date of an event; that is, how prices would have evolved if there had been no shocks (Regression Analysis of Time Series [RATS], 2004; Chopra & Bessler, 2005).

Figure 4 shows the historical decomposition graphs of the three price series for a four-month horizon from RATS software.[8] The dynamic impacts of the shocks can spread over many time periods or dissipate quickly. However, we don't look at prices very far into the future because we are more interested in the contemporaneous nature of their impacts. Further, it is likely that other effects would normally occur after a few weeks or months to cloud their impacts. For this study, we have used a 15-week time period for forecasting and 10 weeks for testing the impact of the BSE shock.

The BSE was discovered on December 23, 2003. Before this date, the actual feedlot, wholesale and retail prices (solid lines), and their forecast prices (dashed lines) followed each other closely with minor differences that are commonly expected between actual price and its forecast. However, they began to depart significantly by the end of December 2003. Historical decomposition of the feedlot prices that includes the impact of the shock showed that the wide departure of actual feedlot prices occurred during the last week of December and reached its maximum by January 10, 2003. It is estimated that the feedlot prices dropped by 21% during this period. Meanwhile, the sharp fall in wholesale prices began by the end of December, almost one week later than the decrease in feedlot prices, and the magnitude was estimated to be about 16%.

In contrast, the largest negative impact of BSE shock on retail prices was only about 6%, which occurred during the week of January 3–10, with an almost one-week lag compared to the decrease in wholesale prices. These results, consistent with the results for speeds of adjustment, show that the beef-safety scare impacts on producers and retailers are quite different. The impact of the BSE shock on feedlot prices (21%), within almost identical time periods, is more than three times that of retail prices (6%). Also, the effect of the beef safety scare on wholesale prices (16%) is more than twice the effect on retail prices, a clear indication of asymmetric price effect with respect to magnitude. These results clearly indicate that in the short run, an exogenous beef safety scare on the U.S. beef sector impacted cattle producers and packers much more severely than beef retailers.

Overall, the historical decomposition results showed, as expected, that the BSE discovery impacted beef prices negatively, but the magnitudes of price effects were substantially different for the three price series, resulting in widening the producer-retail price

[8]The solid line is the actual price which includes the impact of the BSE shock and the dashed line is the forecast of that price excluding the effect of any shock.

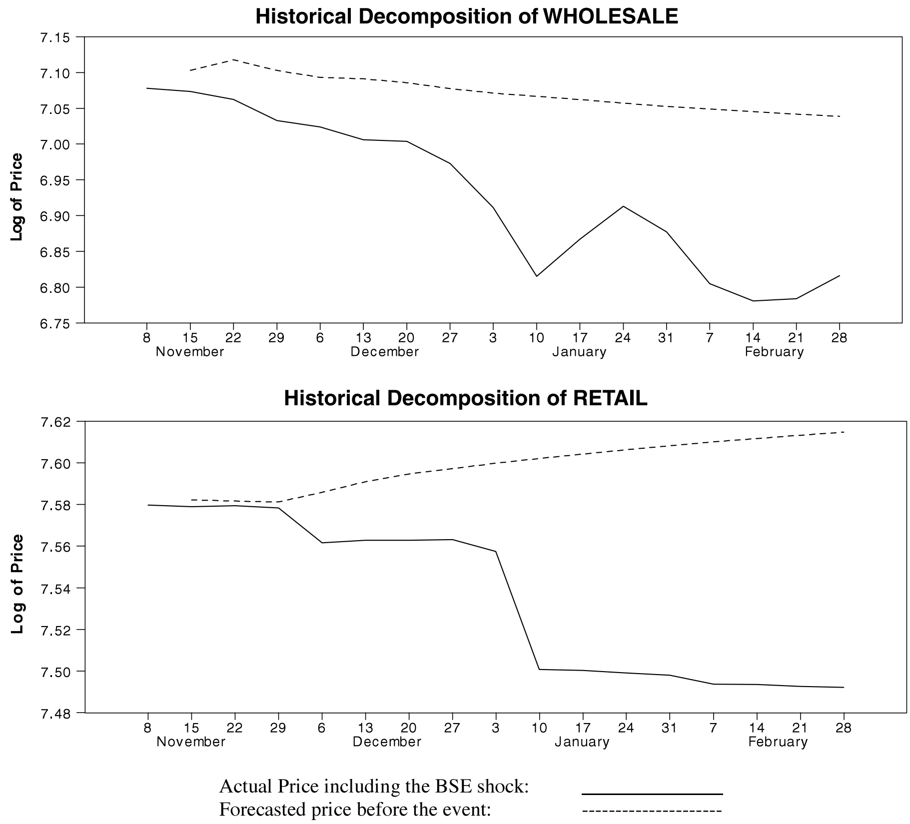

Figure 4 The BSE impact on U.S. feedlot, wholesale, and retail prices in log form.

margins. Also, the effect of the shock on the three price series immediately after the event had about a one-week lag between the stages. Because the BSE discovery was covered by the media and electronic news outlets rather quickly, the estimated one-week lag of the beef safety impact along the supply channel may reflect the role of contracts and the fact that, typically, cattle are bought one week to be slaughtered the next week, rather than reflecting problems with the flow of information through the chain.

These results, consistent with our previous results regarding the differentials speeds of adjustment, suggest stickiness and incomplete price transmission in the U.S. marketing channel. The results again point to the existence of market inefficiency and might be a signal of market concentration and oligopsony behavior at the retail level in the U.S. beef sector. Lloyd et al. (2003), who investigated the impact of the BSE scare in the UK meat market, suggested that market power could influence the retail-farm margin. Their results supported the hypothesis that market power caused the margin between retail and farm prices to widen following a food safety scare. Their results showed BSE crisis reduced the price of beef in the UK, but beef price reduction at the retail level was significantly less than the reduction at the producer level, causing the retail-producer price margin to increase. More research that explicitly incorporates appropriate imperfect competitive and market power analysis is required in order to address the oligopolistic and oligosonistic market behavior in the U.S beef sector.

4. SUMMARY AND CONCLUSIONS

In this article, we investigated how the BSE discovery in the U.S. beef sector affected feedlot, wholesale, and retail beef price series along the U.S. beef supply channel. We applied time series cointegration techniques, vector error correction, directed graphs, Granger causality, and historical decomposition to weekly U.S. beef price series. The objective was to test several fairly important hypotheses.

First, according to traditional price determination theory, price transmission flows downward along the supply chain, i.e., the direction of causality is unidirectional running from producer to retail prices. However, our results rejected this hypothesis for the U.S beef markets, indicating that beef price causality at different stages of the supply channel are bidirectional, influencing and being influenced by each other at each stage. More specifically, the hypotheses that feedlot prices do not Granger cause wholesale and retail prices, wholesale prices do not Granger cause retail and feedlot prices, and retail prices do not Granger cause wholesale prices were all rejected.

Second, concerns have been expressed regarding packer concentration in the beef industry. One hypothesis is that high packer concentration leads to asymmetric price transmission and market inefficiency at the wholesale level. However, the results of the cointegrated VEC model showed that wholesale prices were actually more flexible than retail prices, and the short-run speed of adjustment at the wholesale level was much faster than the one at the retail level, pointing to a relatively high degree of imperfect price transmission at the retail level. Consistent with this finding, Hahn (2004) argues month-to-month meat price changes are due to dynamic adjustments; he showed that livestock and meat prices vary more in the short run than operation costs.

Mathews et al. (1999) also argues that wholesale prices have more variability than retail prices. They further argue that it often seems retail prices follow producer prices and mimic the ups and downs of producer prices with lags of a month or more. Our results confirmed this assertion to a degree. We used weekly, not monthly, data, and historical decomposition graphs showed the lag to be about one week to ten days. However, as discussed previously, this does not mean that price causality is unidirectional from feedlot to wholesale to retail. There exist bidirectional interaction effects.

Third, the historical decomposition results corroborated the results of the VEC model and dynamic speeds of adjustment showing that the burden of the BSE shock was distributed unevenly, with the feedlot and wholesale levels taking most of the burden of the negative shock, falling by more than three to one and two to one, respectively, compared to the fall in the retail prices. Azzam and Anderson (1996), who reviewed the literature on meatpacking industry, also concluded that packers' market power did not increase with higher concentration and argued that increased concentration might be due to the economies of size rather than noncompetitive behavior.

The differential effects of the BSE discovery on the supply channel widen the gross margins between farm and wholesale and wholesale and retail and consequently distort distribution of income in the beef industry. These results suggest the U.S. beef marketing system is hampered with inefficiency and in order to address market inefficiency in the U.S. beef sector, one must draw attention to the retail market. The problem may be concentration and oligopsony power at the retail level. Further research is needed to address these issues.

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