Intertemporal Price Adjustments in the Beef Market: A Reduced Form Analysis of Weekly Data

John M. Marsh and Gary W. Brester

An intertemporal reduced form model is estimated for boxed beef, carcass, and slaughter prices on a weekly basis. The results indicate that prices respond jointly to changes in economic information within weeks t and $t - 1$, supporting time-series studies showing farm and wholesale prices to be nearly instantaneously related. However, the existence of market uncertainty entails significant intertemporal lags, revealed by prices stabilizing 9–14 weeks subsequent to a market shock. The model results imply that postponing marketings of fed cattle to capitalize on expected price advantages would be risky and that selling cattle carcass grade and weight is more favorable when prices respond to increases in beef production.

Key words: beef prices, intertemporal adjustments, reduced form.

Short-term beef price relationships between the farm and wholesale levels of the market have received considerable attention in the literature. Most of these relationships have been investigated via time-series methods, i.e., Granger causality and transfer functions in order to estimate price discovery and lead-lag relationships among cash slaughter, cash carcass, and live cattle futures markets (Koontz, Hudson, and Garcia; Hudson and Purcell; Oellermann and Farris; Spreen and Shonkwiler; Ward 1981). Other time-series studies have dealt strictly with cash price relationships among the farm, carcass, and sometimes retail market levels (Bessler and Brandt; Barksdale, Hilliard, and Ahlund; King; Miller; Boyd and Brorsen; Schroeder and Hayenga). These studies provide useful insight into changing dominant market and price discovery relationships; however, their conclusions have varied due to different sample years, time-series methods, market locations, and data transformations employed.

The objectives of this article are to estimate the weekly behavior of U.S. boxed beef, car-cass, and slaughter steer prices and to analyze the nature of intertemporal price adjustments given changes in value-relevant information. Intertemporal price behavior is measured by weekly distributed lag responses based on a set of reduced form difference equations. The nature of these adjustments are examined via the dynamic patterns of prices that result from arbitrary shifts in market information.

Econometric models using weekly data have not been employed to estimate intertemporal beef price behavior. An econometric analysis of weekly data would extend time-series information by revealing the causes of price responses and provide information about stability adjustments in the beef market. For example, weekly farm and wholesale prices may be nearly instantaneously related as discovered by transfer functions, but little information is provided about the source of these changes or of their time path behavior due to market rigidities such as risk and uncertainty.

Knowledge of such intertemporal price adjustments is important to decision making. Sellers of cattle and beef products usually evaluate expected returns based on different marketing periods and alternative methods of selling. For example, cattle feeders may assess the expected profitability of marketing fed cattle in the current period versus holding cattle for sale at a later date or selling cattle on a carcass

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grade and weight basis instead of liveweight (McCoy and Sarhan). Cattlemen also are concerned about intertemporal price relationships between the boxed beef and live cattle trades. For example, increasing market concentration in meat packing and retailing raises questions as to whether the value of slaughter cattle correlates closely with the wholesale-retail demand for beef cuts. These issues are discussed in the conclusions and implications section.

Model Development

The econometric model used in this study consists of weekly slaughter, carcass, and boxed beef prices that are vertically and intertemporally linked within a set of reduced form equations incorporating market dynamics.[1] The price model is derived from a set of structural demands that initially includes the retail level. Supply equations are not specified since beef supplies are assumed predetermined in the very short run (one week). The demand equations are given as:

(1) $\qquad QDR_t = f_1(PR, PSUB, Y, \mu_1),$

(2) $\qquad QDBX_t = f_2(PBX, PR, W, \mu_2),$

(3) $\quad QDCARC_t = f_3(PCARC, PBX, BPC, W, \mu_3),$
and

(4) $\qquad QDSL_t = f_4(PSL, PCARC, W, BPF, \mu_4),$

where QDR is the quantity of retail beef consumed (mil. lbs.); $QDBX$ is the quantity of boxed beef consumed (mil. lbs.); $QDCARC$ is the quantity of carcass beef consumed (mil. lbs.); $QDSL$ is the quantity of liveweight slaughter cattle demanded (mil. lbs.); PR is the retail price of Choice beef ($/cwt); $PSUB$ is the retail price of the beef substitutes pork, poultry, and lamb ($/cwt); Y is personal disposable income (mil. dollars); PBX is the price of boxed beef, cut-out value of Choice 2-3 beef carcasses, 600–700 lbs., FOB Omaha ($/cwt); W is gross weekly average earnings of nonagricultural, nonsupervisory workers in the private sector (mil. dollars); $PCARC$ is the price of Choice 3 steer carcasses, 600–700 lbs., Omaha ($/cwt); BPC is the price of carcass

byproducts, edible tallow, meat, and bone meal ($/cwt); PSL is the price of Choice 2–4 slaughter steers, 900–1,100 lbs., Omaha ($/cwt); BPF is the price of slaughter byproducts, hide and offal ($/cwt); and μ_1–μ_4 are white noise disturbance terms, i.e., mean zero, constant variance, and no serial correlation.

The structure indicates that retail demand for beef (QDR) is based on the traditional variables of own price (PR), prices of red meat and poultry substitutes $(PSUB)$, and consumer disposable income (Y). The remaining demands are derived and are based on sets of input and output prices, a margin factor, and byproduct values. Thus, the derived demand for boxed beef $(QDBX)$ by retail purchasers depends upon the input price (PBX), the output price of the final retail product (PR), and the margin shifter wages (W). Carcasses are inputs to the processing of boxed beef. Thus, the derived demand for carcasses $(QDCARC)$ is a function of the input price $(PCARC)$ paid by processors and retailers, the value of output price (PBX), the value of carcass byproducts (BPC), and the margin shifter wages (W). The derived demand for slaughter cattle $(QDSL)$ is a function of the live cattle input price (PSL), the output price of carcasses $(PCARC)$, the margin shifter wages (W), and slaughter byproducts (BPF). Overall, the configuration of variables among the markets is consistent with the structural beef models developed by Arzac and Wilkinson; Brester and Marsh; Crom; Freebairn and Rausser; Leuthold; and Marsh and Brester.

In the above demand structure, classes of beef prices are assumed to be jointly dependent. Hudson and Purcell indicate joint dependency occurs since weekly beef prices reflect timely commodity movements and processing activities among the market levels and also interface with futures trading through information changes. The endogenous nature of prices permits specifying a set of inverse demand equations, given as:[2]

(5) $\qquad PR_t = g_1(QBV, QPKL, QPLT, Y, PBX,$
$$PCARC, PSL, \mu_1'),$$

(6) $\qquad PBX_t = g_2(QBV, W, PR, PCARC,$
$$PSL, \mu_2'),$$

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[1] The price of boxed beef should be included in the study since the commodity currently constitutes over 80% of wholesale beef traded (Duewer and Crawford). Boxed beef consists of carcasses that are fabricated into primal and subprimal cuts and vacuum packed for sale, usually to retail outlets. The method offers certain cost advantages through lower transportation, shrinkage, labor, and handling costs per unit of beef output and reduces transaction costs by facilitating retailer demand for specific cuts of beef.

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[2] It is recognized that the cash markets interact in the price discovery process with the feeder cattle and live beef futures markets. However, the thrust of the current analysis is to measure only cash price responses to economic information. Changes in such information influence market participants' buying and selling decisions which result in price changes, whether they be cash or futures prices.

(7) $PCARC_t = g_3(QBV, BPC, W, PR,$
$PBX, PSL, \mu_3'),$

and

(8) $PSL_t = g_4(QBV, BPF, W, PR,$
$PBX, PCARC, \mu_4').$

The following modifications are made in the transition from equations (1)–(4) to equations (5)–(8): (*a*) The *QDR, QDBX, QDCARC,* and *QDSL* variables would normally enter the right-hand sides of the price dependent equations. However, consumption data do not exist on a weekly basis for the first three variables, thus, they are replaced by the quantity of beef and veal produced (*QBV*), Federal Inspected (mil. lbs.). The *QDSL* variable is also replaced by *QBV* since liveweight slaughter and carcass weight production are very highly correlated. (*b*) The PSUB variable in equation (1) is replaced by quantities of competitive meats defined as quantities of pork and lamb produced (*QPKL*), Federal Inspected (mil. lbs.), and quantities of chicken and turkey produced (*QPLT*), Federal Inspected (mil. lbs.).[3] (*c*) Since beef prices are recognized as jointly dependent, each equation also contains beef prices specific to other marketing stages. (*d*) The error terms μ_1'–μ_4' are not identical to those of equations (1)–(4) but are assumed to possess white noise properties.

The econometric analysis does not involve estimating the structural or inverse demand equations. Rather the analysis centers on estimating reduced form prices so as to calculate the direct and indirect distributed lag effects of changes in market information. Thus, beef prices in equations (5)–(8) can be respecified as a dynamic function of all exogenous variables, given as:

(9)
$$P_{it} = \beta_0 + \sum_j \beta_{1j}(QBV)_{t-j} + \sum_j \beta_{2j}(QPKL)_{t-j}$$
$$+ \sum_j \beta_{3j}(QPLT)_{t-j} + \sum_j \beta_{4j}(BPF)_{t-j}$$
$$+ \sum_j \beta_{5j}(BPC)_{t-j}$$
$$+ \sum_j \beta_{6j}(W)_{t-j} + v_{it}$$

$$j = 0, 1, 2, \ldots$$
$$i = 1, 2, 3.$$

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[3] The pooling of the quantities of pork and lamb reduced the number of distributed lags on the exogenous variables and the associated collinearity problems and convergence problems in the nonlinear regression algorithm.

The *i* subscript 1 is price of boxed beef, 2 is price of carcasses, and 3 is slaughter price. The model is concerned only with dynamic behavior of the derived prices, therefore, retail price is omitted as a dependent variable. Note the income variable (*Y*) is omitted since weekly observations are not available. The subscript $t - j$ permits the reduced forms to be estimated as distributed lags due to buyer-seller expectations in price discovery and the time lags involved in responding to market information.

The exogenous variables in equation (9) represent market information (publicly and privately published) that influences buyer-seller price negotiations of live cattle and wholesale beef products. The production variables represent relevant meat quantity information available to market participants in the price discovery process. Production information results in price shifts since participants react to changes in quantities of beef and veal (own production), quantities of pork and lamb (red-meat competitors), and quantities of chicken and turkey (white-meat competitors). Information about the value of carcass and slaughter byproducts is critical to meat packers. Sales of byproducts generate revenue to cover slaughter costs and profits since, oftentimes, the value of live cattle exceeds the value of carcasses (Crom). Cattle feeders who sell fat cattle on the rail also have a vested interest in the value of byproducts since it may influence final settlement price on graded carcasses (McCoy and Sarhan). Wages are specified to proxy the effect of changing packer-to-retailer margins on derived prices, i.e., the effect of marketing costs on inverse derived demand (Tomek and Robinson).

Econometric Implications

Given the specification of equation (9), for *j* large, precise estimates of the β coefficients are difficult to obtain due to collinearity of the lagged variables and reduction in degrees of freedom. One alternative is to specify the system as a set of difference equations, which produces a parsimonious configuration of explicit lags, yet permits sufficient lag responses over the sample period (Kmenta). Specifically, the dynamics are modeled in the regression with relatively short lags on both the exogenous variables and intertemporal dependent vari-

ables and with an ARMA process on the error term. Harvey (pp. 223–25) shows that in a simple two-variable equation such a specification can be represented by:

$$(10) \qquad Y_t = \frac{\alpha(L)}{\beta(L)} X_t + \frac{\rho(L)}{\lambda(L)} U_t,$$

where the systematic dynamics of X_t are represented by the rational lag family of $\alpha(L)/\beta(L)$ and the disturbance dynamics are represented by the ratio $\rho(L)/\lambda(L)$ or an ARMA (p, q). The ratio of the two polynomial lag operators in the regression equation is given as:

$$(11) \quad \alpha(L) = \alpha_0 + \alpha_1 L + \ldots + \alpha_m L^m,$$
$$(12) \quad \beta(L) = 1 - \beta_1 L - \ldots - \beta_n L^n, \qquad m \le n$$

and the lag operators specific to the disturbance structure are written as:

$$(13) \quad \rho(L) = \rho_1 U_t + \ldots + \rho_p U_{t-p},$$
$$(14) \quad \lambda(L) = -\lambda_1 e_{t-1} - \ldots - \lambda_q e_{t-q} + e_t,$$

where e_t is white noise. Using the lag operator notations of equations (11)–(14) and substituting into equation (10) gives an estimatable equation:

$$(15) \quad Y_t = \alpha_0 X_t + \alpha_1 X_{t-1} + \alpha_2 X_{t-2} + \ldots$$
$$+ \alpha_m X_{t-m} + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \ldots$$
$$+ \beta_n Y_{t-n} + \rho_1 U_{t-1} + \ldots + \rho_p U_{t-p}$$
$$- \lambda_1 e_{t-1} - \ldots - \lambda_q e_{t-q} + e_t.$$

The regression function results in the nth order difference equation, and mth order distributed lag on X_t, an autoregressive error of order p, and a moving-average error of order q. The lag operators are also applicable to equations with several exogenous variables. Consequently, the polynomial lag denominator is constrained to all the regressors unless explicitly excluded from the difference equation. For purposes of empirical estimation, specified polynomials of order higher than two or three may not be practical since they seldom generate a meaningful lag distribution that is different than the constrained Pascal distribution (Judge et al.).

The presence of an ARMA disturbance in the stochastic difference equation (15) implies that OLS estimation of the parameters in $\alpha(L)$ and $\beta(L)$ would be inconsistent and asymptotically inefficient (Kmenta). However, most of these nonlinear problems can be overcome by maximum likelihood and nonlinear least squares estimation models (Judge et al.). For the weekly beef model, which is based on the nature of equation (15), nonlinear least squares

is used to obtain consistent least squares estimates of the parameters.

Subsequent to estimating equation (15), the intertemporal market adjustments can be calculated. The adjustment process is based on a set of sequential partial derivatives, or recurrence relations, and is a direct function of the model parameters and roots of the difference equation (Griliches). For example, adding an intercept to equation (15) and letting $m = 1$ and $n = 2$, then

$$(16) \qquad Y_t = \bar{\alpha} + \alpha_0 X_t + \alpha_1 X_{t-1} + \beta_1 Y_{t-1}$$
$$+ \beta_2 Y_{t-2} + \epsilon_t^*,$$

where ϵ_t^* is an ARMA (1, 1). The time path of Y_t, given an exogenous shift in X_t, would follow:

$$(17) \qquad
\begin{aligned}
\frac{\partial y_t}{\partial X_{t-1}} &= \alpha_0 \beta_1 + \alpha_1 \\[4pt]
\frac{\partial y_t}{\partial X_{t-2}} &= \alpha_0 \beta_2 + \alpha_1 \beta_1 \\[4pt]
\frac{\partial y_t}{\partial X_{t-3}} &= \alpha_0 \beta_2 \beta_1 + \alpha_1 \beta_2 \\[4pt]
&\;\;\vdots \\[4pt]
\frac{\partial y_t}{\partial X_{t-6}} &= \alpha_0 \beta_2^3 + \alpha_1 \beta_2^2 \beta_1 \\[4pt]
&\;\;\vdots \\[4pt]
\frac{\partial y_t}{\partial X_{t-10}} &= \alpha_0 \beta_2^5 + \alpha_2 \beta_2^4 \beta_1 \\[4pt]
&\;\;\vdots \\[4pt]
\frac{\partial Y_t^*}{\partial X_t^*} &= \frac{\alpha_0 + \alpha_1}{1 - \beta_1 - \beta_2}.
\end{aligned}$$

The last term represents the convergence of the series to its long-run partial derivative. Given the nature of the difference equation roots (real or complex), the nonlinear combinations of β_1 and β_2 in equation (17) determine how quickly prices would approach an equilibrium state. For β_1 and β_2 positive, smaller (larger) summation values imply more (less) rapid adjustment periods. Similarly, for β_1 positive and β_2 negative, the smaller (larger) is the dampening parameter, β_2, the shorter (longer) is the adjustment period.

Data Considerations

The sample period utilized in the model begins with the first week of January 1982 and ends the last week of December 1985 for a total of 209 weekly observations. This period coincides closely with recent time-series work of

Schroeder and Hayenga. The livestock and meat data were obtained from weekly reports of the U.S. Department of Agriculture's (USDA) *Livestock, Meat, and Wool Market News.* Chicken and turkey production were obtained from the USDA's *Poultry Market News.* All prices were deflated by the Implicit Price Deflator for Personal Consumption Expenditures (1972 = 100), collected from various issues of the U.S. Department of Commerce's *Survey of Current Business.* Data for the wage variable were obtained from the U.S. Department of Labor's *Monthly Labor Review.* The Implicit Price Deflator and wages variables were available on a monthly basis. Therefore, the reported figures were assumed to occur at the midpoint of each month, and weekly estimates were then calculated by linear interpolation.

In several instances, prices for carcass by-products were not reported. There were 10 missing data points, however, they appeared to be randomly distributed over the data set. Linear interpolation was used to complete the observations. The other alternative was to specify binary variables to remove observations that corresponded to the weeks containing missing data. However with dynamics explicit in the model, each equation has a tendency to be overparameterized which can cause convergence problems in the nonlinear regression algorithm. In addition, with an autoregressive error structure, the effects of the missing observation are never completely removed from the dynamics of the equation even when a binary variable is employed.

Empirical Results

Each equation was initially specified with second-order lags on $\alpha(L)$ and $\beta(L)$ with an ARMA (1, 1) disturbance structure. The statistical tests in table 1 indicate second-order difference equations with ARMA (1, 1) disturbances best characterized the behavior of carcass and slaughter prices, and a first-order difference equation without an ARMA process best characterized the behavior of boxed beef price.[4]

The selection of the distributed lags was based on augmenting and truncating the orders of $\alpha(L)$ and $\beta(L)$ and using information about the asymptotic t-ratios and the likelihood ratio test. Asymptotic t-ratios, in conjunction with adjusted R^2s and standard errors of equation, determined the order of $\alpha(L)$. For example, a few lags on the exogenous variables had asymptotic t-ratios less than the 5% level of significance; however, they were retained since their joint combination with other lagged variables yielded superior equation fits and better predictions (turning points) within the sample period. The significance of the parameter lags on the difference equations was determined by a likelihood ratio test at the .95 probability level, with the results showing the relevant first and second orders to be the maximum lag length.

The weekly data fit the functions quite well in that the adjusted R^2s exceed .95, and the ratios of the standard errors of equation to the means of the dependent variables are .018 or less. The difference equations also possess dynamic properties that appear well behaved. That is, for boxed beef price the $|\beta_1|$ is less than unity, while for carcass and slaughter steer prices the roots of $\beta(L)$ are real and positive, with values lying outside the unit circle boundary. Thus, the time path of box price follows a dampening geometric pattern, while for carcass price and slaughter price each time path demonstrates polynomial behavior of the second-order difference equation.

These time path differences are not economically significant. The geometric path of boxed beef price indicates a maximum price effect occurs in period t. The polynomial behavior of carcass and slaughter prices (based on equation (17)) indicates that the maximum price effects occur in period $t + 1$ and then geometrically dampen. The slight differences may reflect the nature of the commodities. For example, the boxed beef market is a primal and subprimal cut trade, which is a different market than the traditional carcass trade. The similar paths of carcass and slaughter prices may reflect their interfacing through formula pricing and selling cattle on the rail (Marsh and Brester; Ward 1979).

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[4] The seemingly unrelated regression problem was examined by testing the cross correlation of the estimated residuals. The results showed that the error covariance structure was not significant. Also, the structural stability of the model was tested by truncating the sample year 1985 and then predicting each week's price based on the parameters of the reduced sample. The result indicated the

structure was quite stable as both the significance and estimated values of the parameters remained intact, and the square of each prediction error was less than the standard error of forecast for each period.

Table 1. Statistical Regression Results of Weekly Boxed Beef, Carcass, and Slaughter Steer Prices

	Equations[a]		
Variables[b]	PBX	PCARC	PSL
Constant	15.548	35.795	29.874
	(2.221)	(2.720)	(3.428)
QBV_t	.0073	.0072	.0059
	(1.783)	(2.736)	(2.740)
$t-1$	−.014	−.0113	−.0053
	(−3.720)	(−3.830)	(−2.848)
$t-2$	—	—	−.0054
			(−2.489)
$QPKL_t$	−.010	—	−.0052
	(−2.068)		(−2.001)
$t-1$	.018	.014	.0048
	(3.705)	(3.597)	(1.945)
$t-2$	—	—	.0096
			(3.605)
$QPLT_{t-1}$	−.0041	−.010	−.0048
	(−1.836)	(−5.043)	(−3.988)
BPC_t	.288	.274	.0748
	(3.286)	(3.708)	(1.452)
$t-1$	−.238	−.169	−.0922
	(−2.638)	(−2.154)	(−1.857)
$t-2$	—	—	.0986
			(2.002)
BPF_t	—	—	.794
			(1.771)
W_{t-1}	−.073	−.213	−.409
	(−1.529)	(−2.346)	(−2.853)
$t-2$	—	—	.217
			(1.598)
β_1 (Dependent	.905	.334	.213
$t-1$ variable)	(34.440)	(3.552)	(2.340)
β_2 (Dependent	—	.503	.563
$t-2$ variable)		(5.914)	(7.217)
AR(1)	—	.434	.514
		(3.578)	(4.395)
MA(1)	—	−.299	−.258
		(−1.779)	(−1.545)

[a] The adjusted R^2 ($\bar{R}^2$), standard error of equation (S), mean of the dependent variable ($\bar{y}$), Durbin's h statistic (Dh), and degrees of freedom (df) for the equations are as follows: 1) Price Box Beef: $\bar{R}^2 = .955$, $S = .870$, $\bar{S}/y = .018$, $Dh = .242$, and $df = 196$; 2) Price Carcass: $R^2 = .971$, $S = .774$, $\bar{S}/y = .017$, $Dh = −.254$, and $df = 194$; 3)Price Slaughter Steer: $\bar{R}^2 = .972$, $S = .459$, $\bar{S}/y = .016$, $Dh = −.102$, $df = 188$.

[b] The asymptotic t-ratios are given in parentheses. The critical t-value for the 95% probability level is 1.98, and for a 90% probability level it is 1.658. The parameters β_1 and β_2 are the first- and second-order difference equation coefficients, and AR(1) and MA(1) are the respective first-order autoregressive and moving-average error terms.

Note: QBV = quantity of beef and veal produced (mil. lbs.); $QPKL$ = quantity of pork and lamb produced (mil. lbs.); $QPLT$ = quantity of chicken and turkey produced (mil. lbs.); BPC = price of carcass byproducts ($/cwt); BPF = price of slaughter byproducts ($/cwt); W = wages; PBX = price of boxed beef ($/cwt); $PCARC$ = price of steer carcasses ($/cwt); PSL = price of slaughter steers ($/cwt).

Most signs of the estimated coefficients agree with a priori reasoning, i.e., negative impacts of direct and competitive production, positive impacts of the values of byproducts, and negative impacts of the margin shifter, wages. The exception is the positive influence of pork and lamb production. This positive sign was also encountered by Freebairn and Rausser and by Marsh and Brester in other econometric work and has often been explained to have a complimentary effect due to variety in diet menu.

The coefficients of the distributed lag model indicate that live cattle, carcass, and boxed beef prices respond relatively quickly to changes in economic information. Specifically, all three prices initially respond to changes in information about beef and veal production, pork and lamb production, byproducts, poultry production, and wages within weeks t and $t - 1$.[5] Week $t - 2$ is also relevant for slaughter price, however, such a response is merely an extension of the distributed lag process that begins within the t and $t - 1$ periods. This implies that buyers and sellers of cattle and beef products have relatively uniform access to information and quickly utilize that information in forming expectations about the future. The results are then reflected in the price discovery process. In addition, the joint price responses reflect relatively quick coordination of input-output activities between cattle feeders and meat packers and processors.

This particular result of the model is significant since price responses tend to support, but not prove, the conclusions of time-series analyses showing farm and wholesale beef prices to be nearly instantaneously related. Conversely, the evidence would not tend to concur with studies showing farm prices to lead wholesale prices by significant amounts (i.e., up to four weeks). One recent article containing information about vertical price relationships is Schroeder and Hayenga. The authors employed Granger causality and transfer functions with first differencing of data to test lead-lag relationships at the farm, wholesale, and

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[5] Note that the positive sign of QBV in week t for each equation may appear contrary to expected negative price effects from an increase in supply in week t. However, in dynamic models of the nature of equation (10) alternating signs often appear in the polynomial numerator but cannot be given an explicit interpretation without conjunctively including the effects of the polynomial denominator. Consequently, it is the summation of the coefficients in the polynomial numerator (negative in this model) that are critical since interaction with the polynomial denominator carries these signs over time.

retail sectors of the beef and pork markets. Their sample period consisted of weekly data from 1983 through 1985, very similar to the sample period of this study. The results specific to the beef market indicated farm and carcass prices were simultaneously related when estimated by transfer functions; however, farm price led wholesale price by almost four weeks using the Granger causality approach.[6]

Table 2 shows the distributed lag effects of the exogenous variables on a percentage basis. These percentage effects are based strictly on estimated distributed lag coefficients that reflect the particular dynamic time paths of beef prices given a permanent, one-week change in an exogenous variable. Thus, they are not equivalent to the traditional direct- and cross-price flexibilities (and demand elasticities) estimated from econometric models based on annual data. A one-week exogenous shock and the subsequent dynamic patterns of prices for 52 weeks would not necessarily equal an annual β coefficient due to different levels of data aggregation and the unique week-by-week time paths of prices.

In general the results indicate that wages dominate the percentage price impacts for all designated months. With the exception of the first month for boxed beef price, the response coefficients for wages exceed unity, while the percentage impacts of the remaining exogenous variables are less than unity. The particular nature of the wages variable may account for its large impact. That is, not only are wages significant as a labor cost factor in the packer-retailer margin but they may also correlate with other cost components in the margin.

The price responses with respect to beef and veal production should be noted. The results indicate a relatively greater response of boxed beef price to beef and veal production compared to those of carcass and slaughter prices (which also did not change with respect to al-

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[6] In this study transfer functions with first differencing of data were also applied to the weekly data. The results (not shown) indicated that slaughter, carcass, and boxed beef prices were simultaneously determined within the same week, which agreed with Schroeder and Hayenga's transfer function results. It should be mentioned, however, that each transfer function demonstrated that the dependent price variable was a function of both the contemporaneous and lagged values of other market price. This suggested that underlying factors such as the variables of the structural model were determining price levels in the transfer functions. Each transfer function consisted of $P_{jt} = f(P_{jt-r}, P_{jt-k}, MA(1))$ for $r = 0, 1, 2$; $k = 1, 2$; and $i \neq j$. Stationarity in the means and variances of the price variables was obtained by first differencing the weekly data, which is the same procedure used in Schroeder and Hayenga's models.

Table 2. Percentage Responses of Boxed Beef, Carcass, and Slaughter Steer Prices to Selected Exogenous Variables

Variables	Periods[a]			
	1 month	3 months	6 months	Long Run
PBX				
QBV	−.117	−.407	−.592	−.643
QPLT	−.116	−.246	−.321	−.353
W	−.702	−1.488	−1.937	−2.131
BPC	.106	.135	.152	.158
PCARC				
QBV	−.052	−.163	−.223	−.245
QPLT	−.204	−.358	−.502	−.539
W	−1.447	−2.846	−3.563	−3.823
BPC	.097	.162	.193	.204
PSL				
QBV	−.061	−.242	−.310	−.325
QPLT	−.135	−.244	−.284	−.292
W	−2.058	−3.375	−3.814	−3.906
BPF	.158	.284	.331	.340

[a] The percentage calculations are based on the formula $\frac{\partial P}{\partial X_{t-j}} \cdot \frac{X}{P}$, where the first term is the cumulative distributed lag coefficient and the latter term is the ratio of the means of the variable.

Note: For explanation of variables, see table 1 note.

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ternative lag orders of $\alpha(L)$ and $\beta(L)$). The response of boxed beef price was directly related to how prices of individual subprimal cuts responded to beef and veal production. Regression work (not shown) showed prices of individual cuts (rib-rolls, chuck-rolls, sirloins) to be quite sensitive to changes in beef and veal production with percentage responses exceeding unity. Heien and Pompelli found in a recent study that the demands for several beef cuts are inelastic and that beef cut cross-price effects are significant.

The lack of identical response behavior among the classes of beef prices should not be surprising since boxed beef, carcasses, and live cattle are different (albeit related) products in the marketing system. Different demand curves exist because of buyer preferences and product services added, which means there is little a priori reasoning as to how the dynamic time paths of these classes of prices should relate exactly. A traditional approach is to link the dynamics by fixed and percentage marketing margins, but as Gardner; Wohlgenant and Mullen; and Wohlgenant (1989) point out, this can be misleading due to parameter sensitivity with changes in processing quantities and the

Table 3. Adjustment Periods for Prices of Boxed Beef, Carcasses, and Slaughter Steers

Variables	Average Adjustment Period	Exogenous Variables[a]		
		QBV	QPLT	W
PBX	13.5	17.5	13.0	10.0
PCARC	12.8	8.5	15.5	14.5
PSL	8.7	8.0	7.0	11.0

[a] All lags are given in number of weeks. These lags indicate the number of weeks it takes each market price to reach a stabilization period when the exogenous variables are increased by the amount of their sample standard deviations. The standard deviations for QBV, QPLT, and W are 32.9 mil. lbs., 40.9 mil. lbs., and $1.72 million, respectively.
Note: For explanation of variables, see table 1 note.

existence of variable proportions in meat processing (substitution of marketing services for farm quantities).

The results also show that the percentage effects of poultry production among the beef prices are not uniform. In particular its impact on carcass price exceeds its impact on boxed beef price, which was consistently reflected by the large poultry coefficient in $\alpha(L)$ of the carcass price transfer function. One reason for this result may be the diminishing importance of the carcass trade relative to the boxed beef trade (Duewer and Crawford). Thus, if poultry production increases (decreasing retail poultry price), the demand for carcasses may realize a relatively larger decrease than the demand for boxed beef.

Overall, the large distributed lag responses of poultry (table 2) demonstrate its strong competitive relationship in the beef market (Marsh and Brester; Wohlgenant 1985). Although these responses are not equivalent to the traditional price flexibilities based on annual models (as discussed above), they do reflect the dynamic sensitivity of beef prices in the first half of the 1980s to upward trends in poultry production and consumption.

Market Adjustments

Though the econometric results infer that market participants quickly assimilate and act upon changes in information, it would be premature to conclude the price adjustment process terminates quickly. The nature of the difference equations indicates the existence of intertemporal lags and somewhat lengthy adjustment periods. Stated another way, market participants quickly react to a change in market news, but due to expectation lags and institutional rigidities, their actions are not fully completed until several weeks expire. Thus, current prices do not exclusively reflect the most current information (Buccola) but rather depend upon a progression of information that begins in earlier periods.

A practical way to evaluate adjustment behavior is to measure the number of weeks it takes beef prices to reach a stabilization period (table 3). In this paper stabilization is assumed to occur when price changes reach an increment of $.05 (5¢) per hundredweight. Most buy-sell transactions at public auctions and between private parties do not involve price increments of less than 25¢ per hundredweight; thus, the arbitrarily low value selected increases the likelihood that the number of weeks reached is a stabilization point in the market. It should be noted that the stabilization periods are not identical to the equilibrium states implied by the long-term percentage responses. The latter essentially are based on zero price changes. According to the distributed lag responses, zero price changes occur in about 38–40 weeks (not shown). However, 38–40 weeks are not equivalent to the long-term adjustments that result from shifts in primary supply due to biological and technical factors inherent in the cattle cycle or from shifts in primary demand due to changes in tastes and preferences.

The adjustment periods are calculated by the distributed lag impacts of three exogenous variables, quantity of beef production, quantity of poultry production, and wages.[7] These variables were selected since they constitute the largest percentage impacts on prices and represent important changes in market information. Each exogenous variable was changed by the value of its sample standard deviation, and the polynomial time paths were then derived, based on equation (17), to discover the number of weeks when prices reached the stabilization criterion.

Table 3 gives the short-term stabilization periods for weekly beef prices. The results show that the major price impacts of changes in eco-

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[7] The marginal impacts of the exogenous variables on each class of beef price were computed by a mathematical algorithm incorporating first-order partial derivatives up to a period of 209 weeks. Equation (17) demonstrates how the marginal impacts would be calculated specific to the example of equation (16).

nomic information are contained within one to two quarters. Specifically, the adjustment processes (averaged over the exogenous variables) show that boxed beef price stabilizes in 13.5 weeks, carcass price stabilizes in 12.8 weeks, and slaughter price stabilizes in 8.7 weeks. In other words if the beef market is disturbed by information pertinent to trading activity, prices immediately respond and then follow dampening polynomial time paths that reach a $.05-per-hundredweight change in about 9–14 weeks.

The intertemporal responses also demonstrate that the weekly price adjustments are not identical among the price categories. For example, the average adjustment difference between boxed beef price and carcass price is less than one week; however, slaughter prices demonstrate a shorter average adjustment period by about four to five weeks.[8] The reasons for the slaughter-wholesale adjustment difference may reflect heterogeneous characteristics of the markets. For example, different decisions are involved in producing, storing, and marketing live cattle by cattle feeders versus intermediate (processed) products by meat packers. Also, packers negotiate with firms in the input and output markets that are characterized by heterogenous market structures, hence, different degrees of market power. The cattle feeding industry (input end) is characterized by a relatively competitive structure, while the retail industry (output end) is characterized by a relatively concentrated structure. Generally, there are more negotiated transactions between packers and cattle feeders; however, there is more formula pricing between packers and retailers (Ward 1979).

Conclusions and Implications

The distributed lag analysis reveals that the source of variation in weekly beef prices is based primarily on economic information. With changes in information, slaughter, carcass, and boxed beef prices jointly respond usually within the first week and no later than

week $t - 1$. These results tend to support time-series analyses showing farm and carcass prices to be nearly instantaneously related. However, the picture is not complete due to the existence of intertemporal lags. Though market traders respond to economic information within the first week, a time process is involved for beef prices to stabilize.

The reduced form model does not reveal all the sources of rigidities in beef price adjustments, however, some practical insights may be offered. First, delays can occur because of the transaction costs associated with different methods of price discovery such as cash negotiation, forward contracting, or formula pricing. Second, the red-meat market structure is not perfectly competitive which implies risk and uncertainty in pricing and production decisions. When market information changes, cattle feeders, meat packers, and retailers are not always certain how each may react, which may result in partial price adjustments as each attempts to protect profit interests in price discovery. And third, traders utilizing weekly information may view its credibility more in terms of the secular outlook. For example, the growth stage of the cattle cycle usually entails periods of increasing prices. Buyers and sellers might behave according to this likely trend and adjust rather cautiously to weekly variations in production.

Producer marketing decisions are often influenced by expectations of short-term price adjustments. Marketing decisions most likely affected would be delayed marketings and selling cattle carcass grade and weight versus live weight. The adjustments of the model suggest that holding finished cattle beyond normal feeding periods to take advantage of maximum price changes could be risky. Market news resulting in a price decrease would not encourage delayed marketings since expectations of a quick price turnaround might not materialize. Market news supporting a price increase could tend to encourage delayed marketings; however, to continue feeding cattle until price is expected to peak would invite yield grade problems (overfinishing).

Concerning selling cattle carcass grade and weight, the carcass and slaughter price responses suggest that periods of increasing beef production might favor selling on the rail, and periods of decreasing beef production might favor selling liveweight. In the former, slaughter price decreases relatively more than carcass

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[8] There are adjustment differences between the sources of information, i.e., *QBV, QPLT,* and *W* in table 3. These differences primarily reflect the values of the estimated coefficients in the polynomial function, $\alpha(L)$, demonstrated in equation (16). The four-to-five week adjustment difference between slaughter price and prices of carcasses and boxed beef was statistically significant when several other selected stabilization values (in addition to the 5¢ per cwt) were used to test for length of stabilization periods.

price, and in the latter, slaughter price increases relatively more than carcass price.

The reduced form analysis also sheds light on a problem that is of concern to cattlemen. They question the relationship between slaughter cattle prices and the value of boxed beef, particularly that price signals between primal and subprimal cuts (components of boxed beef) and slaughter cattle are quite vague. The results of the model suggest that, on a weekly basis, the two price series respond jointly to changes in economic information in such a manner that their price differences demonstrate small variability. The sample data also reflect this in that the standard deviation of the difference between boxed beef and slaughter prices is $2.61 per cwt, or only 6.6% of its mean value, $39.82 per cwt.

It should be noted that the time paths of intertemporal beef prices can also be analyzed in terms of multivariate effects of the exogenous variables. It is quite likely that beef production could increase one week and then decrease the next. Likewise, in any week there could be a concurrent increase and decrease, respectively, in beef production and poultry production. These could be mixed with changes in byproduct values. Such events would yield different net percentage price effects and stabilization periods (compared to *ceteris paribus* restrictions) due to the additive effects of the variables.

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