Price Transmission Asymmetry in Pork and Beef Markets

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Abstract. *Farm, wholesale, and retail prices for beef and pork show significant evidence of asymmetric price interactions. All prices display greater sensitivity to price-increasing shocks than to price-decreasing shocks. The farm beef price, in particular, reacts faster to wholesale price increases than to wholesale price decreases.*

Keywords. *Endogenous switching, pork, beef, asymmetry, price transmission*

The interactions among the farm, wholesale, and retail prices of meats are often controversial, especially when the farm price drops substantially more than the retail price. People often claim that retail prices reflect cost increases more rapidly than cost decreases. This study presents evidence to show that this common suspicion is valid. In the short run, retail prices of beef and pork are more sensitive to price-increasing factors than to price-decreasing factors. Wholesale and farm prices for beef and pork are also more sensitive to price-increasing factors. Both farm and retail beef prices react more strongly to wholesale price increases than to wholesale price decreases.

These asymmetric price responses are measured using a Generalized Switching Model (GSM). Previous research into asymmetric price transmission has been based on Ward's (*13*) Dynamic Asymmetric Markup Model (DAMM).[1]

The GSM is the rough equivalent of a set of unrestricted reduced-form equations for a general set of endogenous switching regressions relating the farm, wholesale, and retail prices of a meat. Although DAMM's are not usually presented as such, they are structural endogenous switching models. Any DAMM can be transformed into a GSM. DAMM's place rather stringent restrictions on the nature of price interactions. The restrictions are that price discovery occurs at the farm level, wholesale prices are determined as a (dynamic, asymmetric) markup over farm prices, and retail prices are determined as a (dynamic, asymmetric) markup over wholesale prices.

GSM's can also be derived from more general models of price interactions. Consequently, GSM's do not require as many assumptions as DAMM's and incorporate a type of asymmetric reaction not found in DAMM's. Price changes in GSM's can be sensitive to their own directions as well as the directions of other prices.

Although the GSM's estimated in this article represent reduced forms, they can be used to make a limited number of inferences about the interaction of prices in the marketing system. The estimates include coefficients which measure the *asymmetry* of interactions between prices. For example, the wholesale price has an asymmetric effect on the farm price if wholesale price increases have a different effect on the farm price than wholesale price decreases. An asymmetric effect implies a nonzero asymmetric interaction coefficient. If the wholesale price has no effect on the farm price, then its effect is symmetric, and its asymmetric interaction coefficient is zero. The reduced-form estimates can be used to test for the existence of asymmetric interactions. If interactions are asymmetric, then they obviously exist. DAMM's imply that wholesale and retail price changes have no effect on the farm price and that retail price changes have no effect on the wholesale price. The significance of these three interaction coefficients can be used as a partial test of the validity of the DAMM's assumptions.[2]

Previous Research

Ward (*13*) invented DAMM's in order to study price transmission in produce markets, extending a methodology devised by Wolffram (*15*). Wolffram's technique involves dividing an independent variable into increases and decreases. Suppose that X_t denotes a variable and DX_t denotes its first difference. Wolffram created four new variables from DX_t: $DXup_t$, $DXdn_t$, $ZXup_t$, and $ZXdn_t$ defined as

$$DXup_t = DX_t \text{ for } DX_t \geq 0, \text{ 0 otherwise,}$$

$$DXdn_t = DX_t \text{ for } DX_t < 0, \text{ 0 otherwise,}$$

$$ZXup_0 = 0,$$

$$ZXup_t = ZXup_{t-1} + DXup_t, \text{ for } t \geq 1,$$

$$ZXdn_0 = 0,$$

$$ZXdn_t = ZXdn_{t-1} + DXdn_t, \text{ for } t \geq 1$$

Note that the following relationship holds between the current value of X and the Z variables

$$X_t = ZXdn_t + ZXup_t + X_0$$

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[1]Italicized numbers in parentheses cite sources listed in the References section at the end of this article.

[2]The space limitations of a journal article prevent a full test of the implications. See (*4*).

Wolffram's procedure involves regressing the dependent variable on Zup_t and Zdn_t. If the coefficients of both Z's are the same, the reaction of Y to changes in X is symmetric. Wolffram's model was first used to analyze irreversible supply by Tweeten and Quance (*9*) and Houck (*6*). Ward extended the Wolffram method by adding distributed lags of the Z variables, allowing lagged price adjustments. Consider the following example of a DAMM model relating the wholesale price to the farm price:

$$\begin{aligned} W_t = {} & A_{wf}Fup_t + Cup_{wf}Fup_{t-1} \\ & + Cup_{wf}ZFup_{t-1} + B_{wf}Fdn_t \\ & + Cdn_{wf}Fdn_{t-1} + Cdn_{wf}Zfdn_{t-1} \\ & + x_tC_w + e_{wt} \end{aligned} \quad (1)$$

W denotes the wholesale price, F denotes the farm price, ZFup and ZFdn are Wolffram-type Z variables constructed from changes in the farm price, x_t is a vector of cost variables and other factors affecting the wholesale/farm margin, e_{wt} is a random error term, and the A's, B's, and C's are parameters. The retail price in time t, which will be included elsewhere in the model, will be denoted by R_t. Equation 1 is somewhat different than the typical DAMM. Ward used distributed lags of the Z variables; and equation 1 uses the Z variables only in the ultimate lags.[3]

DAMM's allow current and lagged farm price increases to have a different effect than current and lagged farm price decreases. The coefficients on the ZF variables measure the ultimate effects of farm price changes on the wholesale price. If the two coefficients are the same, farm price changes have symmetric effects on the longrun wholesale price.[4] Ward's model allows price transmission asymmetry to be a longrun or shortrun phenomenon.

DAMM's have also been applied to modeling retail pricing. The structure of a retail pricing model is similar to that of equation 1, with the retail price replacing the wholesale price as the dependent variable, and functions of the wholesale price replacing farm prices in the set of predetermined variables. DAMM's were used by Boyd and Brorsen (*1*) to study price transmission in pork markets, and by Kinucan and Forker (*8*) who studied price transmission in milk markets.

Previous modelers have estimated DAMM's using least squares. There is potential simultaneity between the farm and wholesale and retail prices which would make least-squares estimates of DAMM's biased and inconsistent. However, if price setting is a recursive process, in which price shocks occur first at the farm level, and spread upwards from there, then DAMM models could be estimated by least squares.

The analyst should check to see if the pricing process is recursive prior to estimating a DAMM. Causality tests can be used to test the hypothesis that pricing is a recursive process (*5*). Heien examined price relationships with mixed results in several agricultural marketing channels. Markup pricing was relatively common but not universal. Wohlgenant showed that under certain restrictive conditions, the farm price would lead retail prices (*14*). His tests demonstrated that monthly farm prices for cattle led retail beef prices. The causality tests used by Heien and Wohlgenant, however, are not appropriate if price interactions are asymmetric. Causality tests are based on linear models, but asymmetric price transmission is a nonlinear process.

DAMM's represent a class of endogenous switching models, where one or more of the coefficients is a function of endogenous variables. The farm price is an endogenous variable whose coefficient in equation 1 switches depending on the direction of the farm price change. While the DAMM represents a particular type of endogenous switching model, it is not the most fully general asymmetric markup model one can derive.

Generalizing the DAMM and Deriving the GSM

A more general version of the DAMM can be written as follows:

Retail Equation

$$\begin{aligned} & Rup_t + B_{rr}Rdn_t + A_{rw}Wup_t + B_{rw}Wdn_t \\ & = Cup_{rw1}Fup_{t-1} + Cup_{rw1}ZWup_{t-1} \\ & + Cdn_{rw1}Wdn_{t-1} + Cdn_{rw1}ZWdn_{t-1} \\ & + Cup_{rr1}Rup_{t-1} + Cup_{rr1}ZRup_{t-1} \\ & + Cdn_{rr1}Rdn_{t-1} + Cdn_{rr1}ZRdn_{t-1} \\ & + x_tC_r + e_{rt} \end{aligned} \quad (2)$$

Wholesale Equation

$$\begin{aligned} & Wup_t + B_{ww}Wdn_t + A_{wf}Fup_t + B_{wf}Fdn_t \\ & = Cup_{wf1}Fup_{t-1} + Cup_{wf1}ZFup_{t-1} \\ & + Cdn_{wf1}Fdn_{t-1} + Cdn_{wf1}ZFdn_{t-1} \\ & + Cup_{ww1}Wup_{t-1} + Cup_{ww1}ZWup_{t-1} \\ & + Cdn_{ww1}Wdn_{t-1} + Cdn_{ww1}ZWdn_{t-1} \\ & + x_tC_w + e_{wt} \end{aligned} \quad (3)$$

[3]This deviation from Ward's methodology simplifies a hypothesis test and reduces multicollinearity because the lagged Z variables are highly correlated.

[4]If equation 1 were written as a distributed lag of Z variables, longrun symmetric effects would imply that the sums of the Zup and Zdn coefficients were the same.

Farm Equation

$$Fup_t + B_{ff}Fdn_t = Cup_{ff,i}Fup_{t-1} + Cup_{ff,i}ZFup_{t-1} + Cdn_{ff,i}Fdn_{t-i} + Cdn_{ff,i}ZFdn_{t-i}\ x_tC_f + e_{ft} \quad (4)$$

For the three-equation system above to represent a true markup process, the error terms of all three equations must be independent of one another

Note how equation 3, the wholesale equation, differs from equation 1 First, equation 3 includes distributed lags of the wholesale price increases and wholesale price decreases This allows for more complex lagged responses More important, the current change in the wholesale price (the endogenous variable) has been split into increases and decreases The coefficient B_{ww} measures the asymmetry of the wholesale price in response to its own direction

The coefficients B_{rr}, B_{ww}, and B_{ff} must all be positive for the system above to be coherent All simultaneous equation systems must meet coherency conditions before they can be estimated (2) Coherency is roughly the opposite of identification Coherency conditions ensure that the model's reduced form can be derived from its structural form Identification conditions ensure that the structural equation can be derived from its reduced form

Coherency ensures that each combination of predetermined variables and error terms implies just one set of endogenous variables Consider the following truncated version of equation 3

$$Wup_t + B_{ww}Wdn_t = \text{(right-hand side)} \quad (3a)$$

If B_{ww} is positive, any value of the right-hand side implies only one solution for the left-hand side When the right-hand side is negative, Wup is zero and Wdn is the right-hand side divided by B_{ww} When the right-hand side is negative, Wup equals the right-hand side and Wdn is zero If the right-hand side is zero, both Wup and Wdn are zero If, however, B_{ww} is negative or zero, equation 3a cannot be solved whenever the right-hand side is negative More than one solution exists when the right-hand side is positive

If B_{ww} is equal to 1, Wup_t and Wdn_t can be rejoined to make the change in the wholesale price and wholesale price changes are symmetric in their own direction B_{ww} allows modeling wholesale price reactions when packers react asymmetrically to changes in total cost and not just to changes in the farm price If B_{ww} is 1, then the terms Wup_t and Wdn_t in equation 3 can be recombined to the change in the wholesale price Whenever B_{ww} is greater than 1, the wholesale price will be more sensitive to price-increasing shocks than to price-decreasing shocks A B_{ww} that is less than 1 implies that the wholesale price is more sensitive to price-decreasing shocks A value of B_{ww} greater than 1 would imply that wholesale prices adjust more quickly upward than downward if other factors (including the effects of lagged wholesale prices) had symmetric effects on the wholesale price

To derive the generalized switching model, note that the system outlined in equations 2, 3, and 4 can be written

$$yup_tA + ydn_tB = x_tC + e_t, \quad (5)$$

where

$yup_t = \{Rup_t, Wup_t, Fup_t\}$,

$ydn_t = \{Rdn_t, Wdn_t, Fdn_t\}$,

e_t is a (1 by 3) vector of error terms,

A and B are (3 by 3) matrices of coefficients,[5]

x_t is redefined to be the vector of all the predetermined variables, including the Z's and lagged increases and decreases, and

C is a matrix of coefficients of all the predetermined variables

The system in 4 would represent a linear system of simultaneous restrictions if the matrix A equaled the matrix B To the extent that A and B differ, price interactions are asymmetric

Not only can the system in 5 represent that of equations 2, 3, and 4, it may also represent other systems of endogenous switching models Any generalization of the system in 5 must also meet coherency conditions The coherency condition for linear simultaneous equation systems is fairly simple The system specified in 3 is a linear system if A and B is equal, and the system will be coherent if the matrix A has full rank If the matrix A has full rank, then one can derive a reduced form If the model is identified or overidentified, the reduced form can be used to derive the structural parameters The requirement of coherency restricts the ranges of the possible values of the matrix A

The coherency conditions also limit the possible ranges of matrices A and B of switching models Note that equation 5 can be written

$$y_tM(y_t) = x_tC + e_t \quad (6)$$

The matrix $M(y_t)$ takes one of eight forms When the retail price is increasing, the first row of $M(y_t)$ is the first row of the matrix A When the retail price is

[5]A and B must meet coherency conditions discussed later

decreasing, the first row of $M(y_t)$ is the first row of the matrix B The second and third rows of $M(y_t)$ depend on the signs of the wholesale and farm price changes, respectively

Gourieroux, Laffont, and Monfort (2) have noted that such endogenous switching models as specified in 5 and 6 are coherent if all their matrices M are of full rank and if all the determinants of the M matrices have the same sign If the model is coherent, the reduced form can be written

$$y_t = M^{-1}(y_t)\,(x_t C + e_t) \quad (7)$$

Coherency conditions restrict the potential ranges of the A and B coefficients For this article, I assumed that meat prices were determined within a coherent system The assumption of coherency is implicit in all applied econometric work The estimation algorithm used in this study can only produce matrices A and B estimates that result in all eight matrices M having positive determinants [6]

The reduced form in 7 is rather inconvenient to estimate, especially for underidentified systems The GSM is a "semireduced" form created by multiplying equation 5 from the right by A^{-1}

$$yup_t + ydn_t B^* = x_t C^* + e_t^* \quad (8)$$

where, B^* is BA^{-1}, C^* is CA^{-1}, and e_t^* is $e_t A^{-1}$

The system in 8 defines the GSM The GSM can be written in expanded form as

$$Rup_t + BrrRdn_t + BrwWdn_t + BrfFdn_t = x_t c_r^* + e_{rt}^* \quad (9)$$

$$Wup_t + BwrRdn_t + BwwWdn_t + BwfFdn_t = x_t c_w^* + e_{wt}^*, \text{ and} \quad (10)$$

$$Fup_t + BfrRdn_t + BfwWdn_t + BffFdn_t = x_t c_f^* + e_{ft}^* \quad (11)$$

Coherency limits the range of allowable B coefficients If the GSM is to be estimated, it must be also be identified Before discussing the identification problem, consider how coherency limits the B estimates

Coherency Conditions

For the GSM to be coherent, the determinants of each of its eight $A(y_t)$ must have the same sign These eight matrices and their associated regimes are

$$M(0) = \begin{bmatrix} Brr, & Bwr, & Bfr \\ Brw, & Bww, & Bfw \\ Brf, & Bwf, & Bff \end{bmatrix}$$

$$Det(M(0)) = Brr{*}Bww{*}Bff - Brr{*}Bwf{*}Bfw + Bwr{*}Bfw{*}Brf - Bww{*}Brf{*}Bfr + Bfr{*}Brw{*}Bwf - Bff{*}Brw{*}Bwr$$

$$M(1) = \begin{bmatrix} Brr, & Bwr & Bfr \\ Brw, & Bww, & Bfw \\ 0, & 0, & 1 \end{bmatrix}$$

$$Det(M(1)) = Brr{*}Bww - Brw{*}Bwr$$

$$M(2) = \begin{bmatrix} Brr, & Brw, & Bfr \\ 0, & 1, & 0 \\ Brf, & Bwf, & Bff \end{bmatrix}$$

$$Det(M(2)) = Brr{*}Bff - Brf{*}Bfr$$

$$M(3) = \begin{bmatrix} Brr, & Bwr & Bfr \\ 0, & 1, & 0 \\ 0, & 0, & 1 \end{bmatrix}$$

$$Det(M(3)) = Brr$$

$$M(4) = \begin{bmatrix} 1, & 0, & 0 \\ Brw, & Bww, & Bfw \\ Brf, & Bwf, & Bff \end{bmatrix}$$

$$Det(M(4)) = Bff{*}Bww - Bwf{*}Vfw$$

$$M(5) = \begin{bmatrix} 1, & 0, & 0 \\ Brw, & Bww, & Bfw \\ 0, & 0, & 1 \end{bmatrix}$$

$$Det(M(1)) = Bww$$

$$M(6) = \begin{bmatrix} 1, & 0, & 0 \\ 0, & 1, & 0 \\ Brf, & Bwf, & Bff \end{bmatrix}$$

$$Det(M(6)) = Bff$$

$$M(7) = \begin{bmatrix} 1, & 0, & 0, \\ 0, & 1, & 0 \\ 0, & 0, & 1 \end{bmatrix}$$

$$Det(M(7)) = 1$$

The matrices have been numbered by counting retail price increases as a 4, wholesale price increases as a 2, farm price increases as a 1, and all price decreases as zeros This numbering system will be retained throughout the article

The matrix M_7, which is associated with all prices

[6] The algorithm takes the logarithm of each estimated matrix M's determinant and will not allow matrices M with negative determinants

increasing, is the identity matrix. Its determinant is 1, a positive number. The other seven determinants must also be positive. Note that the determinants of M_6, M_5, and M_3 are Bff, Bww, and Brr, respectively. Coherency requires that the diagonal elements of the B* matrix be strictly greater than zero.

Reduced-form parameters can be derived from those of the GSM. The reduced-form changes depend upon the directions of the prices in equation 7. The estimated C coefficients and the variance/covariance structure of the GSM are the reduced-form parameters for regime 7, in which all prices are increasing. (The M matrix for regime 7 is the identity matrix, equal to its own inverse.) The estimated B coefficients can be used to derive the reduced forms for the other regimes.

One advantage of using regime 7 as the base regime is that it simplifies the interpretation of the off-diagonal elements of the matrix B. These off-diagonal elements provide a crude measure of the asymmetry of the feedback from one price to another. For example, if farm price increases have a greater initial impact on the wholesale price than farm price declines, then the coefficient B_{wf} will be positive. If farm price declines have a greater initial impact on the wholesale price, then B_{wf} will be negative.

Identification

The identification of the GSM can be demonstrated in two ways. If a system of equations is identified (and coherent), then its maximum likelihood estimates exist and are unique. Maximum likelihood estimation yielded unique values, proving that the system is identified. As more proof of model identification, we see that there are no nontrivial linear combinations of the model's equations that meet the same restrictions as its structural form. All the price increases are multiplied by the identity matrix in the GSM. Any attempt to transform the GSM will produce a model where the price increases are not multiplied by the identity matrix.

Econometric Issues

The GSM's for beef and pork are estimated using a three-stage procedure. In the first and last steps, I estimated the full model by using maximum likelihood estimation (MLE). The intermediate step is a model specification step in which restrictions are placed on the coefficients of the lagged endogenous variables. These restrictions are used in the last stage.

Data and Specifying the Lag Structure

The GSM combines features of switching models and vector autoregressive models. In the GSM, current changes in retail, wholesale, and farm prices are related to lagged price increases and declines, lagged Z variables, an intercept, a trend, and the Consumer Price Index (CPI). The trend and the CPI account for factors that have affected margins over time. Both the pork and beef models used 378 observations of weekly price changes, with the sample period starting in the first week of 1980 (table 1). In initial runs, 6-week lags were used. The model can also be viewed as an asymmetric, rational lag model. Research has indicated that rational lag models with 3 or 4 lags can closely approximate most patterns of lagged adjustment (*3*). So, a 6-week lag should be more than sufficient and may even overfit the model. After the initial runs, the models' specifications were tightened by imposing restrictions on the predetermined variable coefficients.

Given the values of the B coefficients, the C coefficients can be estimated by least squares. So, in the first stage, all the coefficients of the models were estimated by MLE. Then, given fixed estimates of the B coefficients, various restrictions on the C matrices were tested. The restrictions were tested jointly on all three equations using a chi square test with three degrees of freedom and an alpha of 10 percent. A series of restrictions were tested, the least significant was then imposed on the estimates, and the remaining restrictions were retested. The process was repeated until there were no more insignificant restrictions.

Table 1—Data sources and their derivations

The data set contained price and cost data for 378 weeks, starting with the week ending January 5, 1980, and ending with the week of March 28, 1987. Earlier observations were lost because of the lags and difference. The price series is based on the monthly data used by USDA to calculate pork and beef price spreads. Proportional changes in observed weekly prices were used as indices to move the monthly data.

R_t	The weekly retail price indices were taken from national average pork- and beef-cut prices as reported by the Knight Ridder News Service.
W_t, F_t	The farm and wholesale prices for pork and beef were based on prices reported in *Livestock, Meat and Wool News* (*11*). The farm price indices were the seven or eight market barrow and gilt prices for pork and the price of Choice steers in Omaha for beef. The wholesale indices were a weighted average of wholesale pork cuts, and weekly prices for Choice 3 steer carcasses.
CPI_t	Consumer price index in week t. The CPI was collected from selected issues of *Survey Of Current Business*, published by the U.S. Department of Commerce (*12*). Monthly changes in these variables were distributed over weeks.

The restrictions were of two varieties. In the first variety, the coefficient of a lagged variable was set equal to that of the earlier or later lag of the same variable This first set of restrictions can transform the 6-week lags into 5-week or shorter lags In the second set of restrictions, the coefficient for a lagged increase was set equal to that of its matching lagged decline Restrictions of this type imply that the lagged increase and decline have symmetric effects This last set of restrictions is particularly important, for if the coefficients of all the Zup's equal those of the matching Zdn's, then price adjustment is reversible

The model specification procedure selected is rather conservative because it is more likely to reject a restriction Testing based on a fixed B estimate makes a rejection more likely than if the B were allowed to vary Also, for vector autoregression problems, Judge and others suggest the use of the Final Prediction Error (FPE) criteria for model selection (*7*) Given the sample size used in this study, the FPE is more likely to accept a restriction than the likelihood ratio test

Estimating the GSM

The meat price model can be estimated by maximum likelihood if the probability density function (PDF) of the change in prices is known The PDF of the change in prices can be derived from that of the error term by using a generalization of an elementary theorem from mathematical statistics (*9*, p 211) Suppose that the error vector is continuously distributed with probability density function $f(e_t)$, then the probability density function of y_t is

$$f(yup_tA + ydn_tB - x_tC)^*\det(M_i(y_t)), \qquad (12)$$

where the function det() denotes the determinant of a matrix and $M_i(y_t)$ is the matrix M associated with the regime implied by y_t The probability density function implied by equation 12 is discontinuous at each point where a price change is equal to zero Equation 12 holds locally for price changes in the interior of the regimes Given normally distributed errors, the likelihood of observing no change is zero A price that does not change could be arbitrarily called an increase or a decrease

There were weeks when some prices did not change Lumping prices that do not change with either increases or decreases affects the likelihood function by changing the matrix $M(y_t)$ I estimated each model three times to see how sensitive the estimates were to the treatment of zeros First, prices that did not change were called price increases, then unchanged prices were called declines, followed by treating unchanged prices as half increase and half decrease (Table 2 shows how differences in the treatment of zero values affects the specification of the regimes)

While the likelihood function is discontinuous in the price changes as long as zero values are assigned to one orthant or the other, that function is everywhere continuous in its parameters The real problem with the discontinuity of the likelihood function lies in determining the statistical properties of the estimates

Table 2—Regime counts from sample period for pork and beef

Regime	Directions			Counting zeros as		
	Retail	Wholesale	Farm	Increases	Decreases	Averages
Pork data regime						
7	Up	Up	Up	67	65	66
6	Up	Up	Down	24	23	23 5
5	Up	Down	Up	27	23	25
4	Up	Down	Down	74	78	76
3	Down	Up	Up	59	58	58 5
2	Down	Up	Down	33	35	34
1	Down	Down	Up	26	26	26
0	Down	Down	Down	68	70	69
Beef data regime						
7	Up	Up	Up	74	68	71
6	Up	Up	Down	15	13	14
5	Up	Down	Up	26	30	28
4	Up	Down	Down	72	72	72
3	Down	Up	Up	64	64	64
2	Down	Up	Down	27	27	27
1	Down	Down	Up	18	20	19
0	Down	Down	Down	82	84	83

Summary of instantaneous price transmission[1]

	Pork	Beef
	Percent	
Retail and wholesale prices move in same direction	48 8	49 5
Retail and farm prices move in same direction	51 3	55 3
Wholesale and farm prices move in the same direction	71 3	76 7
All three prices move in the same direction	38 4	41 0

[1]Percentages are based on treating no change as half increase, half decrease

Endogenous switching models share a problem in common with logit, probit, and other discrete dependent variable models in that, *a priori*, there is a finite chance that the model will not converge to unique estimates for one or more parameters. In the endogenous switching model, some parameter estimates will not exist if one or more of the prices is monotonic throughout the sample period. This article will use the asymptotic properties of maximum likelihood estimates to justify the hypothesis tests and standard error calculations much the same that applied researchers handle discrete dependent variable models.

I estimated the GSM's under the assumption that the error vectors were independently and identically distributed over time as a multivariate normal process. Given the assumption of normality, the logarithm likelihood function for the switching model for one observation can be written

$$(2\pi)^{-3/2} \det(\Sigma)^{-1/2} \exp(-e_t\Sigma^{-1}e_t'/2)\det(M(y)), \qquad (17)$$

where

$$e_t = yup_t + ydn_tB - x_tC,$$

and Σ denotes the variance/covariance of the error terms and the function exp() denotes the base of the natural logarithms, e, raised to the power in parentheses. The sample likelihood function implied by 17 was used to derive the estimates of the models' parameters.

The Results

The treatment of zeros had little effect on the estimates of either pork or beef models, and no effect on the restrictions implied by the model specification step. Table 3 shows the restrictions on the C coefficient estimates for both pork and beef. The one set of restrictions for both was not sensitive to the specification of the zeros.[7] In the pork model, 63 coefficients were eliminated, and in the beef model, 54 coefficients were eliminated.

Pork prices showed evidence of irreversible price adjustment. Both farm and wholesale price changes had different effects in the long run depending on whether they were increases or declines. Conversely, beef price changes were reversible over the long run. Price increases and declines also showed a different lag structure. For pork, retail price increases affected prices with a 5-week lag. Retail price drops took a full 6-week lag. Wholesale price declines worked through a 4-week lag, and increases through a 5-week lag. Farm pork price increases also worked through a longer lag than declines. Farm price drops had a lag of only 2 weeks, while farm price increases have lagged effects for 5 weeks. The beef price structure had 6-week lags for retail increases and declines and farm price increases. Wholesale prices worked through a 4-week lag. Farm price increases had a 6-week lag, while declines had a 5-week lag.

[7]In fact, when I accidently used pork B's with the beef data, I still got the same set of restrictions on the C matrix that I got with the beef B's.

Table 3—Restrictions on the C parameter estimates[1]

		Pork restrictions			
Rupt-1	Rdnt-1	Wupt-1	Wdnt-1	Fupt-1	Fdnt-1
Rput-2	Rdnt-2	Wupt-2	Wdnt-2	Fupt-2	Fdnt-2
Rupt-3	Rdnt-3	Wupt-3	Wdnt-3	Fupt-3	Fdnt-3
Rupt-4	Rdnt-4	Wupt-4	Wdnt-4	Fupt-4	Fdnt-4
Rupt-5	Rdnt-5	Wupt-5	Wdnt-5	Fupt-5	Fdnt-5
ZRupt-6	ZRdnt-6	ZWupt-6	ZWdnt-6	ZFupt-6	ZFdnt-6
		Beef restrictions			
Rupt-1	Rdnt-1	Wupt-1	Wdnt-1	Fupt-1	Fdnt-1
Rupt-2	Rdnt-2	Wupt-2	Wdnt-2	Fupt-2	Fdnt-2
Rupt-3	Rdnt-3	Wupt-3	Wdnt-3	Fupt-3	Fdnt-3
Rupt-4	Rdnt-4	Wupt-4	Wdnt-4	Fupt-4	Fdnt-4
Rupt-5	Rdnt-5	Wupt-5	Wdnt-5	Fupt-5	Fdnt-5
ZRupt-6	ZRdnt-6	ZWupt-6	ZWdnt-6	ZFupt-6	ZFdnt-6

[1]All variables in a box have the same effect on price system.

Final Stage Estimates

Table 4 shows the B coefficient estimates and Z tests for all the beef and pork models. The Z tests are based on the information matrix. The null hypothesis for the off-diagonal elements is that the coefficient is 0. The diagonal elements are tested against the null hypothesis that the true value of the coefficient is 1.

In all the models, the diagonal elements are greater than 1, implying that prices in meat-marketing channels are more sensitive to price-increasing shocks than to price-decreasing shocks. The B_{rr} for (retail) beef prices and B_{ff} for (farm) pork prices are both around 1.5, implying that these prices are about two-thirds more sensitive to price-increasing shocks than they are to price-decreasing shocks.

In the pork model, only the coefficient B_{ff} is significant at the 5-percent level. Although most of the estimated off-diagonal coefficients are relatively close to zero, the largest in absolute value is the B_{fw}, which measures the asymmetry of the wholesale price on the retail price. This coefficient is -0.16, suggesting that the retail price of pork is somewhat more sensitive to wholesale price declines than to wholesale price increases.

Beef shows larger asymmetry coefficients than pork. Few of these coefficients are significant despite their size. The interaction coefficients in the retail price equation are particularly large. B_{rw} is 0.6 and B_{rf} is 0.5. These estimates imply that the retail price of beef is much more sensitive to wholesale and farm price increases than decreases. These estimates are not, however, statistically significant at the 5-percent level. The one interaction estimate that is significant is that for B_{fw}, which is approximately 0.4. This estimate implies that the farm price of beef is more sensitive to wholesale price increases than to wholesale price decreases. The significant asymmetric effect that the beef wholesale price has on the beef farm price implies that beef wholesale prices are not determined by a markup process. The significance of the coefficient B_{rr} implies that retail beef prices cannot be adequately modeled with the Wolffram/Ward methodology.

The pork and beef estimates imply that retail and wholesale price increases have a larger immediate impact on farm prices than retail and wholesale price declines. Both farm prices are more sensitive to price-increasing shocks than to price-decreasing shocks. Price transmission asymmetry does not seem to be working against producers, at least not in the very short run.

Table 4 contains a joint test of the significance of the B estimates, where the GSM's are compared with an alternative whose B matrix is restricted to the identity matrix. The joint test statistics for both beef and pork

Table 4—B estimates and test statistics for generalized switching models[1]

Coefficient	Zeros are ups		Zeros are half up, half down		Zeros are downs	
	Estimate	Z value	Estimate	Z value	Estimate	Z value
Pork estimates						
Brr	1.1235	1.51	1.1325	1.61	1.1416	1.71
Brw	-.1610	-.71	-.1628	-.72	-.1650	-.72
Brf	.1279	.32	.1400	.35	.1528	.38
Bwr	.1023	1.31	.1044	1.32	.1066	1.34
Bww	1.1479	1.47	1.1520	1.49	1.1555	1.50
Bwf	-.0262	-.08	.0022	.01	.0332	.09
Bfr	.1033	1.60	.1053	1.60	.1073	1.61
Bfw	.0459	.30	.0366	.23	.0262	.17
Bff	1.4657	3.25	1.5062	3.48	1.5481	3.72
Joint test of significance of B estimates[2]	35.04		35.09		35.35	
Beef estimates						
Brr	1.5273	4.70	1.5134	4.64	1.4997	4.57
Brw	.6468	1.79	.6332	1.81	.6193	1.82
Brf	.5334	1.46	.5371	1.49	.5413	1.53
Bwr	-.0596	-.94	-.0581	-.93	-.0565	-.92
Bww	1.1972	1.99	1.1644	1.71	1.1317	1.40
Bwf	-.1418	-1.03	-.1186	-.87	-.0944	-.70
Bfr	.0556	-.67	.0569	.69	.0583	.72
Bfw	.4394	2.50	.3987	2.33	.3571	2.15
Bff	1.2489	1.83	1.2656	1.99	1.2827	2.15
Joint test of significance of B estimates[2]	77.20		76.13		75.35	

[1]Test statistics are based on variances derived from Kramer/Rao lower bound. The null hypothesis for Brr, Bww, and Bff is that the coefficient is 1; the null hypothesis for the other parameter estimates is that they are 0.

[2]Asymptotic chi square with 6 degrees of freedom. 95-percent critical value is 12.6.

are significant at the 0 1-percent level, supporting the hypothesis that asymmetry is an important factor in very shortrun price interactions

Tables 5 and 6 have the C matrix estimates for pork and beef, respectively The lagged retail prices have significant and negative effects in the current retail price equation for both meats, and lagged wholesale prices have negative and significant effects in the current wholesale price equation The farm price equations show fewer significant variables than the others

Conclusions

Pork and beef prices show evidence of asymmetric price interactions Prices at all levels of the marketing channel tend to react more strongly in the short run to price-increasing shocks than the price-decreasing shocks This tendency is most pronounced and most significant in retail prices There is also evidence of asymmetric interactions among the prices

Asymmetry is a significant factor in meat pricing, but

Table 5—C matrix estimates and significance tests for pork GSM[1,2]

	Retail		Wholesale		Farm	
Coefficient	Estimate	Z value	Estimate	Z value	Estimate	Z value
Rup_{t-1}	-0 8676	-12 85	-0 0831	-1 76	-0 0252	-0 64
Rup_{t-2}	-1 2212	-14 15	- 0347	- 57	- 0710	-1 41
Rup_{t-3}&Co	- 5731	-7 84	- 0757	-1 48	- 0612	-1 43
Rup_{t-5}&Co	- 3601	-8 15	- 0479	-1 55	- 0301	-1 17
Rdn_{t-1}	-1 2294	-15 73	- 0343	- 63	- 0300	- 66
Rdn_{t-2}	- 6964	-7 66	- 1354	-2 13	- 0773	-1 46
Rdn_{t-3}	-9 8942	-9 69	- 0750	-1 16	- 1124	-2 09
Wup_{t-1}&Co	0320	39	- 6262	-10 78	- 0885	1 83
Wup_{t-3}&Co	0215	21	- 3865	-5 51	- 1160	1 98
Wup_{t-5}&Co	1109	1 14	- 3121	-4 60	0593	1 05
Wdn_{t-4}&Co	2020	2 09	- 2799	-4 14	0814	1 45
Fup_{t-1}&Co	- 0632	- 54	6783	8 27	3115	4 56
Fup_{t-2}&Co	4938	4 04	- 6737	7 88	0122	17
Fdn_{t-2}&Co	3205	3 83	- 2340	4 00	- 1042	-2 14
Fup_{t-5}&Co	2608	2 53	3643	5 05	- 0780	-1 30
INTERCEPT	13 8124	1 23	-14 4892	-1 84	-8 3507	-1 27
$TREND_t$	1905	2 78	-0 0876	-1 83	- 0001	0
CPI_t	- 0634	-1 39	0575	1 80	0327	1 23

[1]For the B matrix estimates given assumption that zeros are half increase, half decrease
[2]Hypothesis test for fixed B estimate

Table 6—C matrix estimates and significance tests for beef GSM[1,2]

	Retail		Wholesale		Farm	
Coefficient	Estimate	Z value	Estimate	Z value	Estimate	Z value
Rup_{t-1}	-1 6870	-24 20	0 1625	5 39	0 0183	0 47
Rup_{t-2}&Co	-1 5022	-18 52	1119	3 19	- 0198	- 43
Rup_{t-4}	-1 3884	-11 37	- 0651	-1 23	- 0541	- 79
Rup_{t-5}	-1 1329	-8 78	0091	16	- 0943	-1 30
Rdn_{t-1}	- 8099	-10 58	- 0388	1 17	0307	- 71
Rdn_{t-3}&Co	-1 4612	-14 97	0610	1 45	- 0359	- 65
Rdn_{t-5}	-1 2682	-11 09	- 0411	- 83	- 0054	- 08
R_{t-6}	-1 1021	-9 22	- 1184	-2 29	- 1470	-2 19
Wup_{t-1}	- 0915	- 41	- 4307	-4 45	5624	4 47
Wup_{t-2}&Co	6361	3 00	- 5782	-6 31	3097	2 60
Wup_{t-3}	4117	1 73	- 7020	-6 80	0922	- 69
Wdn_{t-1}	3891	1 75	- 8789	-9 14	1698	1 36
W_{t-4}	6050	3 11	- 5237	-6 23	631	58
Fup_{t-1}	- 5833	-3 17	3446	4 33	- 8020	-7 74
Fup_{t-2}	- 3136	-1 36	6100	6 10	- 1107	- 85
Fup_{t-4}	0843	37	- 5418	5 52	0880	69
Fup_{t-5}	- 1432	- 65	2662	2 81	- 2656	-2 16
Fdn_{t-1}&Co	- 1883	-1 19	4505	6 60	- 2127	-2 40
F_{t-6}&Co	0295	17	3746	5 03	- 1073	-1 11
INTERCEPT	-75 7816	-3 72	-15 2946	-1 74	-9 1805	- 80
TREND	- 0692	-3 02	- 0326	-3 29	- 0138	-1 07
CPI	3497	4 09	0699	1 89	0406	84

[1]For the B matrix estimates given assumption that zeros are half increase half decrease
[2]Hypothesis test for fixed B estimate

how does it occur? Further research in this area is warranted Pricing asymmetry could be a rich topic for theoretical and applied research Applying endogenous switching models in future investigations of meat-pricing practices may be useful

The use of semireduced-form endogenous switching models could be applied to the study of other economic variables An obvious area for additional research is price interactions in other agricultural markets This technique can be applied to the study of any set of potentially interrelated variables

Estimating semireduced-form switching models is advantageous because they allow the researcher to make limited inferences about the structure of the underlying system The asymmetric feedback coefficients permit the researcher to demonstrate the existence of feedbacks and to reject model structures which imply no feedbacks from one endogenous variable to another For instance, the estimates from this article imply that the farm level is not the center of price discovery in short run beef markets

This research can be extended to alternative models of price discovery No level has been eliminated as a center of price discovery in pork markets, and retail or wholesale levels are still candidates for beef markets

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