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An Empirical Analysis of the Demand for Wholesale Pork Primals: Seasonality and Structural Change

Joe L. Parcell

This study focuses on estimating wholesale pork primal demand relationships in order to determine their own-quantity flexibilities, whether these flexibilities have changed over time, and seasonal price fluctuations. A set of equations for pork loin, rib, butt, ham, pork belly, and picnic primals was estimated. Monthly data over an 11-year period were used to determine that own-quantity flexibilities varied across months, that they increased in absolute value over time for some primal cuts, and cold-storage stocks were used as an inventory control measure to reduce price variation for some primal cuts.

Key words: seasonality, structural change, wholesale pork primals

Introduction

Meeting final demand and processor needs is increasingly more important in agriculture. In particular, the pork industry underwent considerable organizational change to better meet final demand. Between 1994 and 2000, the level of vertical coordination in the hog industry increased from 6% to 24% (Grimes and Meyer). Processors are expanding into the branded and case-ready pork market, and swine producers are organizing processing cooperatives to add value to their hogs. As more emphasis is placed on capturing value along the pork marketing chain, the swine industry faces greater pricing challenges. Given increased market coordination, persons associated with the wholesale pork market require a better understanding of how structural change affects pricing decisions.

The objectives of this research are to determine factors affecting wholesale pork primal prices, examine whether own-quantity flexibilities change between periods in the year, and determine whether own-quantity flexibilities have changed over time for pork loin, rib, butt, ham, pork belly, and picnic wholesale pork primals.[1]

Based on a review of the literature, no previous study has estimated individual wholesale pork primal price flexibilities or causes of price variability (i.e., seasonality and retail-level factors).[2] Yet, the pork industry is showing more interest in the farm-to-

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[1] These wholesale primals account for over 55% of the live weight carcass.

[2] As a measure of this variability over the past 10 years, the nominal wholesale price of pork loin ranged between $75/cwt and $145/cwt with a coefficient of variation of 0.12, and the wholesale nominal price of pork belly ranged between $25/cwt and $65/cwt with a coefficient of variation of 0.32.

wholesale and wholesale-to-retail segments of the market chain. Why? Decisions such as cold-storage capacity, seasonal marketing contracts with producers and retailers, and the development of specialized markets are used in negotiating prices, controlling costs, and strategic planning. Three recent events in the pork industry indicate interest in the wholesale pork market. The Excel Corporation converted an 8,000-head-per-day slaughter facility to a further processing facility. Both Smithfield Foods and Tyson purchased existing further processing facilities for cut-specific and brand-name products. And the National Pork Producers Council has placed high priority on the further development of producer-owned hog-processing cooperatives.

Some economists openly state that the elasticity of demand for retail pork products has became more inelastic over time (Plain and Grimes).[3] Statements, like those made by Plain and Grimes, use nonstochastic analysis; yet, the implications of these statements are important. First, if the demand for pork products has became more inelastic over time, then discount specials on pork at the retail level will have less of an impact on the quantity demanded today than in the past. In separate studies, Goodwin and Holt, and Schroeder and Mintert found that the flow of price information tends to be unidirectional up the marketing chain in the meat industry. Thus, demand responses at the retail level, as determined by previous research, may or may not be appropriate for extension to the wholesale pork market. Examining factors which determine wholesale pork primal prices and quantifying the extent to which demand elasticities for pork primals have changed over time will help retailers, wholesalers, producers, processors, consultants, and economists make better management and marketing decisions and recommendations.

Previous Research

Capps et al. empirically analyzed the factors affecting changes in monthly wholesale prices of beef primals for the 1980–1990 period. They regressed the wholesale price of primal cuts on lagged own-price, per capita own-quantity, per capita quantity of other beef cuts, pork, and poultry, a marketing cost index, and a series of monthly dummy variables. Capps et al. found own-quantity flexibilities differ among primals. They report there was relatively no cross-flexibility effect from changes in the level of other beef, the marketing cost index effect was positive, cross-flexibility estimates of pork and chicken differed by beef primal, and seasonal variation exists among different beef primals.

Parcell and Pierce analyzed the demand for broiler and turkey wholesale primals. Assuming fixed proportions between the farm and wholesale levels, they estimated inverse demand models using monthly data between 1988 and 1998 in a seemingly unrelated regression framework. They found seasonal differences for various broiler and turkey primals, and own-quantity flexibility was shown to differ between primals.

Hahn and Green empirically tested the assumption of fixed proportions between the wholesale and retail levels by estimating inverse aggregate wholesale beef, pork, and chicken demand models. The price of the wholesale product was specified as a function

[3] For instance, high-protein/low-carbohydrate diets have increased in popularity. Some experts suggest a diet of increased bacon consumption because it is high in protein and low in carbohydrates. Thus, the demand for bacon possibly changed due to consumer attitudes regarding red meat.

of own-retail price, a double-differenced own-wholesale price, pork quantity, beef quantity, chicken quantity, CPI, and wage. Hahn and Green estimated an aggregate own-quantity flexibility for pork of -0.0621 and a positive and negative cross-price elasticity for beef and chicken, respectively. Neither the CPI nor wage variables were statistically significant, and they failed to reject the hypothesis of fixed proportions between the wholesale and retail levels.

In a recent study, Lusk et al. estimated wholesale models for Choice and Select beef. They specified demand models for wholesale Choice and Select beef as a function of own-wholesale prices, wholesale prices of competing meats, quarterly intercept shift variables, and a time trend variable. Lusk et al. also estimated models with interaction terms between wholesale prices and quarterly intercept variables. An elasticity of demand for Choice beef was estimated to be -0.432, and an elasticity for Select beef was -0.633. Their system results indicated an aggregate wholesale pork elasticity of demand of -0.471. The demand for Choice and Select beef increased in quantity over time. The own- and cross-price elasticities were found to vary seasonally. During the second and third quarters, both the Choice and Select own-price elasticities were inelastic. Intuitively, these periods correspond with the time of year when beef is in greatest demand and the summer grilling season. Lusk et al. estimated the cross-price elasticity between Choice and Select to be 0.196 and the cross-price elasticity between Select and Choice to be 0.269.

The Conceptual Model

This study uses the conceptual model developed by Wohlgenant for analyzing farm- and retail-level demand for various commodities. He used a retail shift index to account for changes in the demand for substitutes and income at the consumer level. Wohlgenant also used production, per capita consumption, and a marketing cost index to explain variation in farm and retail hog and pork prices.

The current study focuses on the wholesale pork sector. However, the retail sector is included in the derivation of the structural model to better motivate the conceptual model. Assuming perfect competition in the input and output markets, the structural model used for this analysis is as follows:

(1) $Q_w^d = \Sigma D_w^i(P_w, P_r, C_w)$ (wholesale demand),

(2) Q_w^s, predetermined (wholesale supply),

(3) $Q_r^d = D_r(P_r, Z)$ (retail demand),

(4) $Q_r^s = \Sigma S_r^i(P_r, P_w, C_r)$ (retail supply),

(5) $Q_w^d = Q_w^s = Q_w$ (wholesale market-clearing condition),

(6) $Q_r^d = Q_r^s = Q_r$ (retail market-clearing condition),

where Q_w^d and Q_w^s are wholesale demand and supply quantities, P_w and P_r are the wholesale and retail prices, C_w and C_r are the wholesale and retail marketing costs, Q_r^d and

Q_r^s are the retail demand and supply quantities, and Z is an exogenous retail demand shift index.

Using the market-clearing conditions (5) and (6), the structural system in (1)–(4) may be rewritten as a two-equation system:

$$Q_w - \Sigma D_w^i(P_w, P_r, C_w) = 0, \tag{7a}$$

and

$$\Sigma S_r^i(P_r, P_w, C_r) - D_r(P_r, Z) = 0. \tag{7b}$$

Following Wohlgenant, equations (7a) and (7b) are totally differentiated, expressed in elasticity form, and solved using $d\ln(P_r)$ and $d\ln(P_w)$. This yields the following:

$$d\ln(P_r) = \mathrm{E}_{rz} * d\ln(Z) + \mathrm{E}_{rc} * d\ln(C_r) + \mathrm{E}_{rw} * d\ln(Q_w), \tag{8a}$$

and

$$d\ln(P_w) = \mathrm{E}_{wz} * d\ln(Z) + \mathrm{E}_{wc} * d\ln(C_w) + \mathrm{E}_{ww} * d\ln(Q_w), \tag{8b}$$

where

$$\mathrm{E}_{rz} = -Q_{ww}^D Q_{rz}^D / K, \tag{9a}$$

$$\mathrm{E}_{rc} = (Q_{ww}^D Q_{rc}^S - Q_{rw}^S Q_{wc}^D)/K, \tag{9b}$$

$$\mathrm{E}_{rw} = Q_{rw}^S / K, \tag{9c}$$

$$\mathrm{E}_{wz} = -Q_{wr}^D Q_{rz}^D / K, \tag{9d}$$

$$\mathrm{E}_{wc} = \left[Q_{wr}^D Q_{rc}^S - (Q_{rr}^S - Q_{rr}^D) Q_{wc}^D\right]/K, \tag{9e}$$

$$\mathrm{E}_{ww} = (Q_{rr}^S - Q_{rr}^D)/K, \tag{9f}$$

and

$$K = -(-Q_{rr}^S - Q_{rr}^D) Q_{ww}^D + Q_{rw}^S Q_{wr}^D. \tag{9g}$$

The variables in equations (9a)–(9g), with expected signs shown in parentheses, are as follows: Q_{ww}^D (−) is the elasticity of wholesale-level demand with respect to wholesale price; Q_{rz}^D (+) is the elasticity of retail-level demand with respect to the retail demand shift index; Q_{rc}^S (?) is the elasticity of retail supply with respect to retail marketing cost; Q_{rw}^S (−), assuming the wholesale product is a normal good, is the elasticity of retail supply with respect to wholesale price; Q_{wc}^D (?) is the elasticity of wholesale demand with respect to wholesale marketing cost; Q_{wr}^D (+) is the elasticity of wholesale demand with respect to retail price; Q_{rr}^S (+) is the elasticity of retail supply with respect to retail price; and Q_{rr}^D (−) is the elasticity of retail demand with respect to retail price.

Expected signs of elasticities listed in equations (9a)–(9g) enable signing the elasticities in equations (8a) and (8b). Given that K is negative, E_{rz} and E_{ww} are negative, E_{rw} and E_{wz} are positive, and E_{rc} and E_{wc} cannot be signed because the signs of Q_{rc}^S and Q_{wc}^D are ambiguous.

The Empirical Model

Using monthly data over the 1989–1999 period, regression models are estimated for each wholesale pork primal price following from (8a) and (8b). For this analysis, models are specified as first-differences of the natural logarithm of the variable.[4] The logarithmic functional form is chosen so that parameter estimates are flexibilities.[5] The first-difference logarithmic inverse demand model for wholesale pork primal price j is specified as:

$$\text{(10)} \qquad \Delta\ln(P_{jt}) = \mathrm{E}_{jz} * \Delta\ln(Z_t) + \mathrm{E}_{jc} * \Delta\ln(C_t) + \mathrm{E}_{jQ} * \Delta\ln(Q_{jt}) + \Sigma_k \mathrm{E}_{jk} * QUART_k + \mathrm{E}_{jDUM} * DUM + \mathrm{E}_j + {}'\Omega_{jt},$$

$$j = \text{pork loin, rib, butt, ham, pork belly, and picnic;} \quad t = 1, 2, 3, \ldots, T.$$

Equation (10) is used to state that the variability in monthly wholesale pork primal price is a function of a retail demand shift index (Z), a marketing cost index (C), the own-quantity of primal cut j (Q), a binary seasonal variable ($QUART$), a binary variable to represent the change in price quote effective January 1998 (DUM), and a constant (E); ${}'\Omega_{jt}$ is a random i.i.d. normal disturbance term. The dummy variable for the change in price quote (DUM) equals 1 for January 1998, and 0 otherwise. Table 1 provides a description of variables and summary statistics for the inverse wholesale pork primal demand models.

For the retail demand shifter, Wohlgenant suggests totally differentiating retail demand for the jth primal and allowing the retail demand shift variable to equal the residual of the left-hand side [$d\ln(Q_j)$] less the own-price elasticity multiplied by the differentiated logarithm of the own-price [$e_{jj} * d\ln(P_j)$]. Thus, the retail demand shifter is specified as:

$$\text{(11)} \qquad \Delta\ln(Z_t) = \Sigma_l e_{jl} * \Delta\ln(P_{rlt}) + e_{jy} * \Delta\ln(Y_t) + \Delta\ln(POP_t),$$

where e_{jl} is the cross-price elasticity of competing meat l, P_{rlt} is the retail price (r) of meat l at time t, e_{jy} is the income elasticity of pork, Y_t is per capita income at time t, and POP_t is the resident population at time t. Elasticity estimates from McGuirk et al. are used in the computation of (11).

To determine whether the own-quantity flexibility varies between months in the year, (10) was modified by adding an interaction term between the own-quantity variable and the quarterly shift variable. This interaction allows for the estimation of quarterly own-

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[4] Each wholesale primal price series was transformed by the natural logarithm operator and tested for stationarity using the augmented Dickey-Fuller. The lag order was determined by minimizing the Akaike Information Criterion. The Dickey-Fuller test statistic was -1.61 for pork loin, -1.89 for boston butt, -1.55 for pork rib, -1.05 for ham, -2.01 for pork belly, and -2.82 for boneless picnic, and the 10% critical value was -2.57. Therefore, the null hypothesis of a unit root for five of the six price series could not be rejected. The first-differenced price series were found to be stationary for all of the primal price series. By first-differencing the data, the flexibilities give instantaneous relative or short-run impacts.

[5] A Box-Cox transformation procedure was used to evaluate the choice of functional form. Results of the Box-Cox test indicated the data preferred the logarithmic functional form. For all but pork loin, the log-likelihood function for the logarithmic functional form, specified by $\lambda = 0$, is less than 3% greater than for the value of λ found to minimize the log-likelihood function. For pork loin, a linear functional form is preferred; however, the percentage difference in the likelihood function is 5%. A full summary of the Box-Cox test statistics between alternative choices of λ is available from the author upon request.

Table 1. Description of Variables and Summary Statistics: Inverse Wholesale Pork Primal Demand Models

Variable	Description	Expected Impact on Pork Primal Price (sign)	Average	Std. Dev.
j	Pork primal cut j, where j = pork loin, boston butt, pork rib, ham, pork belly, boneless picnic			
t	Month t between February 1989 and December 1999 (t = 1, ..., 131)			
P_{jt}	Wholesale price of pork primal cut j in month t ($/cwt):			
	Pork loin		106.62	12.39
	Pork rib		111.49	15.20
	Boston butt		68.99	12.57
	Ham		65.92	12.45
	Pork belly		49.10	15.89
	Boneless picnic		62.62	8.83
Q_{jt}	Average daily per capita pork consumption, adjusted for pork imports, exports, and primal j change in cold-storage stocks, in month t (lbs./capita/day):	(–)		
	Pork loin		0.179	0.074
	Pork rib		0.176	0.074
	Boston butt		0.182	0.013
	Ham		0.173	0.080
	Pork belly		0.174	0.086
	Boneless picnic		0.180	0.073
C_t	Food marketing cost index (energy cost index, 1992 = 100) in month t	(?)	187.85	24.02
Z_t	Retail demand shifter: summation of cross-elasticities of demand multiplied by the retail price of competing good, plus the income elasticity of pork multiplied by the sum of per capita income, plus population in month t	(+)	21.25	0.07
DUM_t	A 0 or 1 binary variable indicating a change in the specification of the wholesale price quote for the different primal cuts (= 1 for January 1998, 0 otherwise)	(?)		
$QUART_{kt}$	Separate 0 or 1 binary variables for quarter k (k = 1, 2, 3, 4; default = $QUART_1$)	(?)		

quantity flexibility estimates for each wholesale primal cut j. The specification of this model is as follows:

$$\text{(12)} \qquad \Delta\ln(P_{jt}) = E_{jZ} * \Delta\ln(Z_t) + E_{jC} * \Delta\ln(C_t) + \Sigma_k E_{jkQ} * \Delta\ln(Q_{jt}) * QUART_k + \Sigma_k E_{jk} * QUART_k + E_{jDUM} * DUM_t + E_j + {}'\Omega_{jt},$$

where variable definitions for equation (12) are as defined in equation (10).

The flexible least squares (FLS) estimator is used to test for parameter stability over time. Tesfatsion and Veitch; Lutkepohl; and Dorfman and Foster provide extensive descriptions of the FLS estimator. The FLS estimator detects parameter instability which may indicate possible structural change in the analyzed variable. Tests for structural change (e.g., CUSUM, Chow, and Recursive Residual tests) provide insight for partitioning the data. These methods, however, do not show the rate at which structural

change occurs or the length of occurrence when there is a temporary structural change. Furthermore, partitioning the data can cause degrees-of-freedom problems when using a small sample size.

Graphically depicting how the wholesale own-quantity flexibility changes over time can be useful in assessing structural change, and the FLS estimator allows for such a graphical representation. The graphical representation suggests inferences regarding potential structural changes that may cause the own-quantity flexibility estimate to change temporarily or persistently.

A brief description of the FLS estimator is given here. Assume a simplified inverse wholesale demand model like the following:

$$P_t = \beta Q_t + \varepsilon_t, \tag{13}$$

where P_t is the wholesale price at time t ($t = 1, ..., T$), Q_t is wholesale demand at time t, and ε_t is a random disturbance term. By allowing the coefficient β to vary over time, the FLS estimator minimizes the loss function derived from (13), which can be specified as:

$$\sum_{t=1}^{T} (P_t - \beta_t Q_t)^2 + \lambda \sum_{t=1}^{T-1} (\beta_{t+1} - \beta_t)' \mathbf{D} (\beta_{t+1} - \beta_t), \tag{14}$$

where β_t is a $\{T \times 1\}$ vector of time-varying parameter estimates, λ is a value between zero and one $[\lambda \in (0,1)]$, and $\mathbf{D}$ is a $\{T \times T\}$ weighting matrix. The first term is the sum of squared errors. The second term is the sum of squared parameter variations over time. The matrix $\mathbf{D}$ is specified as a positive definite diagonal unit matrix with diagonal elements $d_{ii} = 1$.[6,7] Given the specification of (14), a large λ penalizes parameter variability and a small λ allows for greater parameter variability. For the FLS estimator, pork primal inverse demand models are estimated separately.

Because wholesalers and retailers trade wholesale primals, exogenous shocks may have a similar impact across wholesale pork primal prices. Using the Breusch-Pagan test statistic for a diagonal covariance matrix, the null hypothesis of a diagonal covariance matrix is rejected (table 2). The seemingly unrelated regression (SUR) estimator was used to improve estimation efficiency. Table 2 lists Durbin-Watson test statistics for the presence of autocorrelation, an inherent problem with time-series data. The size of the Durbin-Watson test statistic for each model suggests autocorrelation is not a concern.

As previously stated, the supply of pork has been assumed to be predetermined. To verify this assumption, a test of exogeneity using the Wald test statistic was performed (Greene, p. 619). The test statistic is distributed chi-squared with one degree of freedom; the critical value was 3.84 at the 5% level. An instrument for the per capita consumption variable was constructed by using all other exogenous variables listed in (10) and a lagged per capita consumption variable for the individual primal. For each of the test statistics computed, the null hypothesis of exogeneity of the pork primal per capita consumption variable was not rejected.[8]

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[6] Poray, Foster, and Dorfman specify the weighting matrix such that diagonal elements associated with the seasonal shift variables do not allow for time-varying parameter estimates. They note that the seasonal shift variables potentially pick up all of the variation. Through visual inspection of the FLS estimator, it was determined the seasonal shift variables do not sufficiently capture the coefficient variability of the other variables.

[7] A positive definite $\mathbf{D}$ matrix ensures a minimum is obtained in the loss function.

[8] Care is taken in the interpretation of the Wald test statistic for endogeneity, as it is not considered a powerful test. However, the level of the test statistics computed here—below one—provides a strong argument that a more powerful test statistic will produce a similar result.

Table 2. Inverse Wholesale Demand Model: SUR Estimates (Dependent Variable = Wholesale Price of Pork Primal Cut)

Variable	Pork Loin	Boston Butt	Pork Rib	Ham	Pork Belly	Boneless Picnic
Own-Cut Flexibility	-0.489**	-0.490***	0.029	0.053	-0.270*	-0.244***
	(<0.01)	(<0.01)	(0.71)	(0.68)	(0.08)	(<0.01)
Index of Marketing Costs	0.534	0.678	-0.449	-0.121	-0.353	0.097
	(0.20)	(0.24)	(0.20)	(0.84)	(0.62)	(0.75)
Retail Shift Index	0.054	0.005	0.322***	0.231*	0.219	0.149**
	(0.56)	(0.97)	(<0.01)	(0.09)	(0.17)	(0.03)
January 1998 Primal Specification Dummy	0.062	0.097	0.005	0.128	-0.069	0.007
	(0.40)	(0.34)	(0.94)	(0.23)	(0.58)	(0.89)
Q_2 (dummy)	-0.008	0.080***	-0.003	0.014	0.006	0.018
	(0.67)	(0.01)	(0.86)	(0.63)	(0.87)	(0.22)
Q_3 (dummy)	-0.025	-0.047*	-0.138***	0.059**	-0.038	-0.014
	(0.18)	(0.07)	(<0.01)	(0.03)	(0.23)	(0.30)
Q_4 (dummy)	-0.058***	-0.002	-0.622***	0.019	-0.063*	-0.029*
	(0.01)	(0.93)	(<0.01)	(0.54)	(0.07)	(0.05)
Constant	0.023*	-0.008	0.513***	-0.025	0.031	0.007
	(0.08)	(0.66)	(<0.01)	(0.20)	(0.17)	(0.50)
R^2	0.97	0.93	0.98	0.92	0.86	0.98
Durbin-Watson Statistic	2.78	2.81	2.48	2.18	2.15	2.28
No. of Observations[a] = 131						
Breusch-Pagan test statistic for a diagonal covariance matrix = 709.28 (15 df)						

Notes: Single, double, and triple asterisks (*) denote statistical significance of the coefficients at the 10%, 5%, and 1% levels, respectively. Numbers in parentheses are p-values.
[a] Observations refer to monthly observations between February 1989 and December 1999.

For the seasonal variation model (12), the same statistical procedures described above were followed. The seasonal variation models were estimated jointly using the SUR estimator. Pork supply was found to be exogenous. Durbin-Watson test statistics indicated residual autocorrelation was not a concern. All models and statistical tests were estimated using SHAZAM 8.0 (White et al.).

Data

The averages and standard deviations of data used in the estimation of the inverse wholesale pork primal demand models are reported in table 1. All series are monthly data from February 1989 through December 1999, yielding 131 observations. The U.S. Department of Agriculture's (USDA's) Livestock Marketing Information Center (LMIC) provided the monthly wholesale primal prices for pork loin, pork rib, boston butt, ham, pork belly, and boneless picnic.

Average monthly per capita pork consumption for the different meat types is calculated as pork production adjusted for pork imports, exports, and the between-month change in cold-storage stocks for each specific wholesale pork primal. Monthly pork production was adjusted by the domestic resident population and the number of days in the month. LMIC also supplied the production, import, and export data. USDA's *Cold Storage* reports provided cold-storage stocks information. For pork rib, USDA did not keep cold-storage values over the entire time period. Thus, constant proportions are

assumed between pork production and the quantity of pork rib. Average daily pork consumption among the six different wholesale primals only varies by the difference in beginning and ending cold-storage stocks within a given month.

Earlier studies either assumed fixed proportions between the farm and wholesale levels (Lusk et al.; Parcell and Pierce), or suggested fixed proportions as a result of estimated models (Capps et al.). Previous research analyzing the fixed-proportions hypothesis between levels in the meat marketing chain is mixed (e.g., Hahn and Green; Wohlgenant; Wohlgenant and Haidacher). The current study uses a combination of the fixed proportion assumption (aggregate pork production) and the variable proportion assumption (change in cold-storage stocks for individual pork primals) to formulate a per capita own-quantity demand variable.

The food marketing cost index is monthly (as published in the USDA's *Agricultural Outlook*). LMIC provided data for the national monthly average retail prices for pork, chicken, ground beef, and steak. U.S. population and U.S. disposable income are monthly annualized values (Federal Reserve Bank of St. Louis). Following research by Peterson and Tomek that suggested deflating may cause autocorrelation and introduce a deterministic trend in the error vector, nominal values are used to avoid introducing model misspecification.[9]

Results

Estimation results for wholesale pork demand are given in table 2. The explanatory variables account for between 86% and 98% of the variation in the different wholesale pork primal prices.

The own-quantity price flexibility is statistically significant and of the expected sign for four of the six wholesale primal cuts. Pork loin and boston butt have price flexibility estimates around -0.49, and pork belly and boneless picnic show price flexibility estimates of approximately -0.25. This result is consistent with the difference between relatively higher value cuts and lower value cuts found for other meat wholesale cuts (e.g., Capps et al.; Lusk et al.; Parcell and Pierce). Neither the pork rib nor the ham price flexibility is statistically significant. There is not a detectable wholesale price response associated with a change in the quantity demanded for these products. Assuming the inverse of the flexibility is the lower limit of the elasticity, the size of the price flexibility for the different primals is significantly different than the aggregate price elasticity of -0.471 estimated by Lusk et al. This finding is inconsistent with economic theory—i.e., aggregates are less elastic (more inelastic) because of fewer substitutes. Hence, this result does suggest it is important to analyze wholesale pork primal prices separately.

A 1% increase in the marketing cost index does not have a statistically significant impact on any of the wholesale pork primal prices. Likewise, Hahn and Green did not find the marketing cost index to be statistically significant in explaining the variability

[9] One reviewer expressed concern over the use of nominal values. Peterson and Tomek cautioned that the use of real price data could result in inefficient standard errors. Thus, as further support for the use of nominal values, a J-test between the nominal price model and a real price model was conducted. For H_1: nominal prices are appropriate, the p-values for the null hypothesis of $\alpha = 0$ were 0.165 for pork loin, 0.499 for boston butt, 0.439 for pork rib, 0.774 for ham, 0.905 for pork belly, and 0.463 for boneless picnic. For H_2: real prices are appropriate, the p-values for the null hypothesis of $\alpha = 0$ were 0.167 for pork loin, 0.502 for boston butt, 0.420 for pork rib, 0.775 for ham, 0.955 for pork belly, and 0.482 for boneless picnic. The results of the J-test, albeit a relatively weak test, indicated either nominal or real prices could be used without any loss of efficiency.

of the aggregate wholesale primal price. Limited variability in the food marketing cost index over the period of the current study could account for the lack of statistical significance.

The retail demand shift variable is statistically significant for three of the six equations. The sign on the coefficient, when statistically significant, was as expected. The retail shift index is the largest in magnitude for pork rib and ham. Because the primary focus of this study is on determining seasonal variability and changes over time in the price flexibility, the retail shift index coefficient is not decomposed.

The dummy variable for the change in specification of the USDA wholesale primal price is not statistically significant for any of the wholesale pork primal price equations. Even though there is a noticeable change in each of the pork primal price levels, transforming the price data using natural logarithms and first-differences likely reduces the impact of the price quote specification change in the multivariate analysis.

For the quarterly intercept shift variables, statistical significance and magnitude of effect varies by wholesale primal cut. Relative to the first quarter, the price for four of the six pork primals is statistically lower during the fourth quarter. This result is consistent with the exogenous seasonal change in pork production.

Seasonal Variation in Own-Flexibilities

Table 3 lists SUR estimates of equation (12) in which the price flexibilities vary between quarters of the year. The results presented in table 3 only differ from those in table 2 by the inclusion of interaction terms between price flexibility and quarterly dummies of the price flexibility and seasonal shift interaction terms. The explanatory variables account for between 86% and 98% of the variability in the wholesale pork primal prices over the period evaluated.

For pork loin, boston butt, and boneless picnic, seasonally varying price flexibility estimates generally are statistically different from zero. A paired t-statistic between the price flexibility for each quarter reported in table 3 and the single primal flexibility reported in table 2 was computed. Using the paired t-statistic, the null hypothesis that the quarterly price flexibilities (table 3) equal the nonvarying flexibility estimate (table 2) are equal is rejected.[10] Thus, the price flexibility for some wholesale pork primals varies within the year. This result is consistent with the findings of Lusk et al. for Choice and Select beef.

Time Path of Wholesale Primal Flexibilities

This study used the FLS estimator to graphically represent the time path of the different pork primal price flexibilities. The FLS estimator is used to estimate the model specified in equation (10). Figure 1 depicts the time paths of the price flexibilities for boston butt, boneless picnic, pork belly, ham, and pork loin, at $\lambda = 0.001$. The weighting coefficient, $\lambda = 0.001$, is chosen to give the model the most flexibility. As λ becomes larger, the FLS estimator approaches the OLS estimator, and the standard errors on the

[10] For pork loin, the test statistic for test of means was 7.88, 1.83, 5.92, and 1.01 for the first, second, third, and fourth quarters, respectively. For boneless butt, the test statistic for test of means was 3.52, 3.02, and 0.47 for the first, second, and fourth quarters, respectively. For boneless picnic, the test statistic for test of means was 9.99 and 3.12 for the first and second quarters, respectively. Statistical significance follows from the t-statistic critical values.

Table 3. Inverse Wholesale Demand Model Allowing Flexibilities to Vary by Quarter: SUR Estimates of Equation (12) (Dependent Variable = Wholesale Price of Pork Primal Cut)

Variable	Pork Loin	Boston Butt	Pork Rib	Ham	Pork Belly	Boneless Picnic
Own-Cut Flexibility						
$Q_1^{flexibility}$	-1.058**	-0.982***	-0.093	0.008	-0.604	-0.619***
	(<0.01)	(0.01)	(0.67)	(0.98)	(0.17)	(<0.01)
$Q_2^{flexibility}$	-0.434***	-0.710***	-0.125	-0.138	-0.081	-0.306***
	(0.01)	(<0.01)	(0.40)	(0.59)	(0.79)	(0.01)
$Q_3^{flexibility}$	-0.312**	-0.135	0.187	0.104	-0.265	-0.085
	(0.03)	(0.50)	(0.13)	(0.63)	(0.29)	(0.42)
$Q_4^{flexibility}$	-0.542***	-0.539*	0.052	0.282	-0.216	-0.188
	(0.01)	(0.07)	(0.28)	(0.36)	(0.55)	(0.21)
Index of Marketing Costs	0.542	0.850	-0.326	0.098	-0.425	0.205
	(0.21)	(0.15)	(0.37)	(0.88)	(0.57)	(0.51)
Retail Shift Index	0.007	-0.072	0.285***	0.179	0.208	0.095
	(0.95)	(0.60)	(<0.01)	(0.22)	(0.22)	(0.18)
January 1998 Primal Specification Dummy	0.055	0.091	0.004	0.129	-0.074	0.002
	(0.45)	(0.37)	(0.95)	(0.23)	(0.55)	(0.97)
Q_2 (dummy)	-0.006	0.072***	-0.009	0.005	0.014	0.015
	(0.79)	(0.01)	(0.60)	(0.88)	(0.71)	(0.32)
Q_3 (dummy)	-0.028	-0.055**	-0.142***	0.058**	-0.380	-0.017
	(0.13)	(0.03)	(<0.01)	(0.03)	(0.23)	(0.19)
Q_4 (dummy)	-0.056***	0.003	-0.059***	0.023	-0.060*	-0.027*
	(0.01)	(0.91)	(<0.01)	(0.44)	(0.09)	(0.07)
Constant	0.022*	-0.100	0.051***	-0.026	0.029	0.006
	(0.09)	(0.59)	(<0.01)	(0.18)	(0.19)	(0.54)
R^2	0.97	0.93	0.98	0.92	0.86	0.98
Durbin-Watson Statistic	2.79	2.78	2.46	2.21	2.16	2.23
No. of Observations[a] = 131						
Breusch-Pagan test statistic for a diagonal covariance matrix = 330.30 (15 df)						

Notes: Single, double, and triple asterisks (*) denote statistical significance of the coefficients at the 10%, 5%, and 1% levels, respectively. Numbers in parentheses are *p*-values.

[a] Observations refer to monthly observations between February 1989 and December 1999.

coefficient decrease in value rapidly. As observed from figure 1, the price flexibility remained fairly constant for all cuts until 1997. After the beginning of 1997, the wholesale primal flexibilities, other than pork belly and ham, became significantly more flexible (increased in absolute value), particularly during 1998.

Given that the price flexibilities began increasing (in absolute value) in 1997 (figure 1), not all of the change can be attributed to the large supply of hogs entering the market in 1998. Demand factors such as advertising campaigns, change in consumer diet, and case-ready and branded products possibly led to this change.

For boston butt, the price flexibility in 1999 was estimated to be five times greater in absolute value than that observed in the early sample period. However, the price flexibilities for pork belly and ham are relatively unchanged, or increase slightly, over the entire period. One possible explanation for the unchanged price flexibilities of wholesale pork belly and ham stems from a build-up of cold-storage stocks of pork belly and ham during the time corresponding to late 1998.

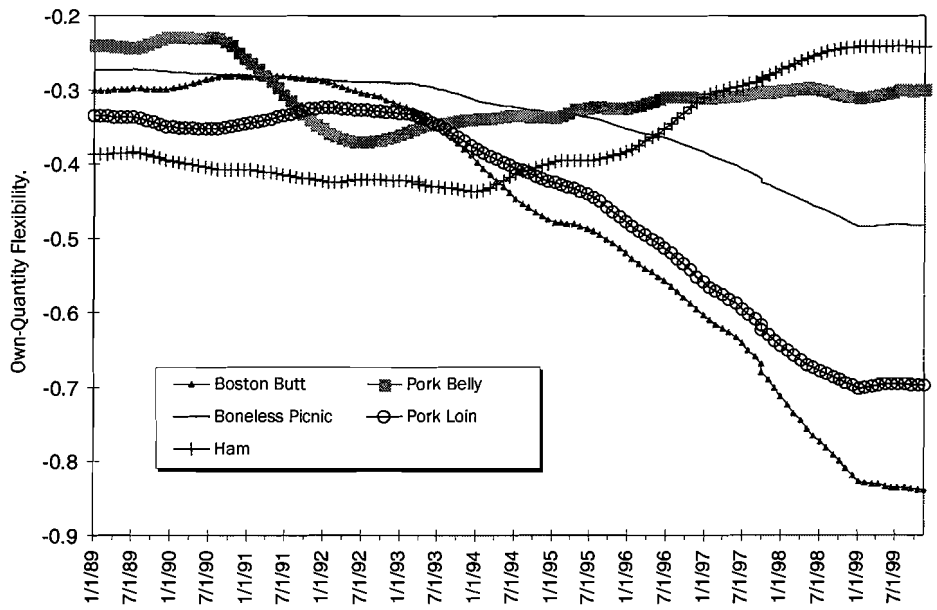

Figure 1. Monthly time path of wholesale pork primal flexibilities from flexible least squares estimator, $\lambda = 0.001$

Conclusions

The present study estimated inverse wholesale pork primal demand models for pork loin, boston butt, pork rib, ham, pork belly, and boneless picnic to analyze whether there is a seasonal component to wholesale price flexibility and to determine whether the own-quantity flexibilities increase in magnitude (absolute value) over the sample period 1989–1999. Results show that the price flexibility varies by wholesale primal; there is a seasonal variation in the own-quantity flexibilities of pork loin, boston butt, and boneless picnic; and their price flexibilities have increased in magnitude (absolute value) over time. Demand factors such as advertising campaigns, change in consumer diet, and case-ready and branded products may have led to this change. Likewise, some observed change in price flexibility was probably due to the "oversupply" of hogs during the fourth quarter of 1998. However, the observed magnitude of change in price flexibility is significantly less than the level of the absolute increase in live-hog price flexibility observed in the fall of 1998 (Parcell, Mintert, and Plain).

For pork loin, boston butt, and boneless picnic, the estimated first-quarter price flexibility is greater than twice the magnitude of the estimated price flexibility when seasonal fluctuations are not accounted for. During other periods within the year, the difference in magnitude is less. The present study found the price flexibility for boston butt increased in absolute magnitude by about a factor of five during the past two years, from -0.30 to around -1.50. However, the price flexibilities of pork belly and ham were either unchanged or increased only slightly over the period of study. The relatively longer period that pork bellies and ham can remain in cold storage likely allows for inventory adjustments to offset any potential large price fluctuations.

Three results of this study are of particular interest:

- First, the disaggregated price flexibilities estimated are significantly different than aggregate wholesale price flexibilities reported in previous research.
- Second, the findings suggest there is seasonal variability in the magnitude of a wholesale primal price response corresponding to changes in quantity demanded. This result is important because it provides industry persons with information on pricing strategies, helps them make better quarterly cash-flow and income projections, and suggests future research analyzing structural change and market power needs to consider seasonality.
- Finally, parametric analysis was used to validate claims that the wholesale-level own-quantity flexibility has increased in absolute value over time. However, the change over time in own-quantity flexibility magnitude is not uniform across wholesale pork primals.

Some limitations of this study are related to the assumed nonseparability among wholesale pork primals due to data limitations. Second, a proxy variable was used for the own-quantity of the different pork primals. Third, fixed proportions were assumed. While numerous researchers have tested the assumption of fixed proportions, Hahn and Green note most tests are indirect. Future research could empirically test the fixed-proportions hypothesis by using cold-storage stocks of individual pork primals as a proxy for own-quantity versus pork production at the farm level.

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