Journal of Agricultural and Resource Economics 25(1):109–127

Joint Costs in Meat Retailing

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A dynamic econometric model relating wholesale meat prices to retail prices and wholesale meat demand is estimated using monthly data on U.S. prices and quantities of beef, pork, and chicken. The hypothesis that meat retailing costs are separable is rejected; that is, the data support joint costs in meat retailing. The hypothesis that there are fixed proportions between wholesale meat inputs and retail meat outputs is accepted.

Key words: beef, chicken, derived demand, joint costs, pork, price transmission, retail meat margins

Introduction

Meat and livestock pricing is a perennial source of controversy in the United States, and producer groups' concerns about livestock pricing issues are often translated into government action. The 1996 report by the U.S. Department of Agriculture's (USDA's) Grain Inspection, Packers and Stockyards Administration (GIPSA) is a recent example of producers' concerns leading to federal action. According to the GIPSA report, much of the controversy tends to focus on the possible abuse of market power by an increasingly concentrated meat packing industry. However, the USDA's own estimates of price spreads in red meats show that the largest part of the farm-to-retail margin is between wholesale and retail levels. The economic performance of meat retailing may be more important to livestock producers than the performance of the packing sector, and hence the importance of understanding the cost structure of meat retailing and its implications for meat marketing margins.

In this analysis we are particularly interested in answering two questions. The first is whether or not margins for one meat affect margins for others. More specifically, do high margins for one species imply high or low margins for others? The second question of interest is whether fixed proportions or variable proportions are valid in the transformation of wholesale meat into retail meat. USDA's price spread statistics are based on the notion that it takes a fixed amount of animal to produce a pound of wholesale meat, and some fixed amount of wholesale meat to produce a pound of retail product. Some research (Wohlgenant; Wohlgenant and Haidacher) has provided indirect evidence that the assumption of fixed proportions is not valid for the entire farm-to-retail marketing chain.

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To answer these two questions, this study develops an econometric model of wholesale-retail price interactions for beef, pork, and chicken using monthly data. Previous applied studies of marketing margins or price interactions tend to fall into two broad classes, and this study combines features from both. One class of marketing margin study focuses on derived demand, while the other class focuses on the dynamics of price formation and transmission. The model used in this analysis is based on retail stores' derived demand for wholesale meat and allows the estimation of long-run demand flexibilities. A unique feature of this model is that it allows for joint costs in meat marketing. Joint costs can lead to cross-species margin effects in the long run. Also, if there are joint costs, it is possible to distinguish a fixed-proportion technology from a variable-proportion technology.

It is common to find evidence of dynamic price adjustment in monthly data, but the derived demand model in this study is a static model. The model is modified using a new variation on an approach developed for adding dynamic adjustments to consumer demand functions.

Previous Literature

Marketing margins have been a popular topic of study by agricultural economists. Schwartz and Willet's bulletin lists and describes a range of these studies. Most applied studies of marketing margins start from the same theoretical foundation, that is, with the consumer demand for food, and a description of the marketing technology. Gardner is often credited with developing the theoretical basis for market margins research. From this basis, studies of marketing margins have tended to branch in two different directions.

One approach consists of econometric studies that estimate price transmission and lead/lag relationships between prices at various marketing levels with only an indirect appeal to microeconomic theory. Two examples of this type of work in meat markets are studies by Boyd and Brorsen, and Hahn. Both of these investigations found significant evidence of dynamic price adjustment, and both found evidence that the dynamics of price adjustment were asymmetric, i.e., it takes longer for retail prices to adjust to farm or wholesale price declines than to increases. Boyd and Brorsen estimated a model of pork price interactions, while Hahn estimated separate models for pork and beef. This focus on a single species or food product is a common feature in studies of this type.

Price transmission studies that include cross-product effects are less common. In our review of the literature, the only example we found of a price-transmission study with cross-margin effects is Griffith, Green, and Duff's analysis of wholesale-to-retail meat margins in Sydney, Australia. Their model allowed for lagged price transmission and cross-margin effects. They found statistically significant evidence of lagged price transmission, but none for cross-margin effects.

Most price lead/lag studies are based on the assumption that it takes a fixed amount of farm (or wholesale) input to produce the associated retail output. With constant returns to scale in food marketing, the long-run retail price will be the farm price (adjusted for the weight change in transformation) plus the costs of transforming and marketing. There is some indirect evidence that the assumption of fixed proportions is not valid.

The other type of margin study starts with consumer demand and a description of a marketing technology, and then builds a system of linked equations that estimate retail and lower-level elasticities of demand and price transmission elasticities. This type of approach generally relies on data on farm or some other upstream input, retail output, and farm (or other upstream) and retail prices. While the USDA publishes statistics on retail food consumption, the agency does not actually measure retail stores' sales of foodstuffs. Rather, the USDA calculates retail consumption based on farm production, stock changes, and net trade using fixed-proportion relationships between farm input and retail output. If there are actually variable proportions between farm input and retail food output, then true retail food output is not properly inferred.

Work done by Wohlgenant, and expanded upon in Wohlgenant and Haidacher, was designed to test if farm-to-retail food production was actually consistent with fixed proportions. Wohlgenant and Haidacher used microeconomic theory to develop an econometric model that linked farm-level demand, farm-to-retail price transmission, and a (potentially) variable-proportion farm input to retail output relationship. They then estimated a set of farm demand and farm-to-retail price transmission equations using annual data. Their elasticity estimates were more consistent with variable proportions for beef and pork than with fixed proportions. Their results for chicken implied a fixed-proportions relationship.

Wohlgenant, and Wohlgenant and Haidacher examined farm-to-retail relationships for evidence of fixed proportions using an indirect test that does not require observations on retail quantities. The USDA and other government agencies publish estimates of live-weight slaughter and carcass-weight meat production, and these data allow for more direct estimates of substitution effects in the farm-to-wholesale part of the beef and pork marketing chain. Evidence of variable proportions in this segment of the marketing chain is mixed. Mullen, Wohlgenant, and Farris found that the ratio of farm beef input to wholesale beef output varied systematically with the farm price of beef. This systematic variation is evidence of the substitution of marketing inputs for live cattle in the production of carcass beef. They estimated that the lower bound for the elasticity of substitution of marketing inputs and live cattle in the production of retail beef was -0.1. This lower bound was based on the assumption that there is no substitution between marketing inputs and wholesale beef in the production of retail beef. Their estimated elasticity of substitution between live cattle and marketing inputs in the production of wholesale beef was larger (in absolute value) than -0.1.

Two more recent, related studies that used plant-level data found much smaller substitution effects in beef slaughter (MacDonald et al.) and pork slaughter (MacDonald and Ollinger). The estimated substitution between inputs and cattle in the production of beef was zero, and a very small elasticity of substitution was found between hogs and capital in the production of pork (-0.07).

Another study has found evidence of variable proportions in the wholesale-to-retail transformation of beef. Brester and Wohlgenant estimated a model that related wholesale beef supply, wholesale beef demand, and (unobserved) retail beef demand, and found that the estimates were consistent with variable proportions in the production of retail beef from wholesale beef. The model presented here is similar to that of Brester and Wohlgenant in that it does not require fixed proportions, or observations of the "true" retail output. However, our model is more general as it incorporates more species' meats, it allows for joint costs in the marketing of these meats, and it does not require the assumption of fixed proportions. Also, Brester and Wohlgenant's model required the estimation of wholesale supply and retail demand parameters. In contrast, the functional form selected for this study can estimate and test features of meat retailing technology without requiring estimates of wholesale supply and retail demand parameters. In special circumstances, the model can distinguish between fixed and variable proportions in meat retailing.

In order to combine the structural-model approach with the price-dynamics approach, we modify a technique used by Anderson and Blundell to add dynamic features to consumer demand models. Microeconomic theory often imposes restrictions on demand and supply functions. In this analysis, micro-theory implies homogeneity and symmetry restrictions. Anderson and Blundell argue that the restrictions of comparative static microeconomic theory represent a long-run equilibrium position and that dynamics arise from the transition to that equilibrium. So, the restrictions of micro-theory should hold in the long run, but might not in the short run. Anderson and Blundell demonstrate it is possible to impose micro-theory restrictions on general, dynamic structures, but the most direct way of doing so leads to inconvenient, nonlinear restrictions. The authors then show some simple data transformations that allow one to impose the long-run restrictions using more convenient nonlinear restrictions. The models they developed resemble error-correction or cointegration models. Anderson and Blundell's models were estimated by nonlinear, seemingly unrelated regressions.

The model in this study will be estimated by three-stage least squares. Because we use a simultaneous equation estimator, it is possible to modify Anderson and Blundell's transformation, basically doing it backwards, to obtain a model without nonlinear restrictions on the long-run coefficients. The disadvantage of this approach is that the dynamic behavior of the model is now a nonlinear function of the coefficients.

Modeling Approach

Rather than start with consumer demand, this study will focus on the retail store and its technology. The costs of producing retail meat from wholesale meat and other inputs should determine (along with wholesale-level supply and consumer demand) the relationship among retail meat supply, retail meat prices, wholesale meat demand, wholesale meat prices, and the prices and demands for other inputs. For the sake of generality, this study allows for meat retailing to be a joint-cost activity. If there are joint costs, there will be some relationship between the wholesale-retail margins of the three meats in the long run.

To test hypotheses about meat retailing technology, this study estimates an inverse derived demand for wholesale meat. The version of derived demand used here is not derived from consumer demand; it is the retail stores' demand for wholesale meats that is derived from the costs or profits of selling retail meats. This inverse derived demand model relates the wholesale price of a meat to the retail prices of all meats, the wholesale demand for all meats, and input costs.

This derived inverse demand is not one of the two types of input demand generally used in econometric studies; however, this form was chosen to avoid problems with data availability and potential technical problems. One common type of input demand is derived from cost minimization. In this formulation, the quantity of wholesale meat demanded depends on the quantity of retail meat supplied and the wholesale price. (The retail price of a meat is the marginal cost of producing that meat.) The problem with this approach is that if there are variable proportions, then retail meat output is not observed, so retail output cannot be used as an explanatory variable.

The other type of input demand equation commonly used is derived from profit maximization. In this type of demand function, the inputs demanded are a function of the wholesale price of the inputs and the retail price of the output. This type of derived demand will not exist if meat retailing has a constant-returns-to-scale production technology.

To avoid the two problems of (potentially) unobserved retail quantities and the nonexistence of profit-maximizing demand functions, the modeling approach used here starts with the cost-minimizing demand functions and the marginal cost (retail price) functions and inverts them, solving for the wholesale prices and the (possibly unobserved) retail quantities as functions of the retail prices and wholesale quantities. The equations that relate the wholesale prices to retail prices and wholesale quantities form the basis for the long-run model of price interactions.

Restrictions on Inverse Wholesale Demand

Constrained optimization implies restrictions on the derived inverse demand functions which will be imposed on the model's long-run coefficients. Derived inverse demands should be homogeneous of degree one in prices and symmetric in quantities.

The derived inverse demand system used in this analysis is based on two underlying assumptions: first, that the costs of retailing meat are separable from the rest of retailers' activities and, second, that the market-level relationships between quantities and prices have the same restrictions as the firm-level relationships. Let the terms $\mathbf{P}_w$, $\mathbf{P}_r$, $\mathbf{Q}_w$, and $\mathbf{Q}_r$ represent three-element vectors that contain wholesale and retail prices, and the wholesale and retail quantities of beef, pork, and chicken. Individual elements of the vectors will be denoted by lowercase letters with additional subscripts. For instance, $p_{w,b}$, $p_{w,p}$, and $p_{w,c}$ are the respective wholesale prices of beef, pork, and chicken. The term $\mathbf{P}_m$ will be used to denote a vector of input costs.

The costs of retailing a certain quantity of meat can be generically expressed as $C(\mathbf{Q}_r, \mathbf{P}_w, \mathbf{P}_m)$. The function $C(\cdot)$ can represent either a joint-cost or a separable-cost technology. There is one assumption made about the form of the cost function. It is assumed that the cost of producing one retail meat is independent of the wholesale prices of the other meats. While this cost function does not rule out variable proportions in the production of retail meat from wholesale meat, it does rule out, for example, using wholesale beef to produce retail pork.

The optimal level of retail output can be determined by setting the marginal cost of producing an output equal to its price. Then, given that optimal output, the optimal demand for inputs is the derivative of the cost function with respect to the input price. Alternatively, under the constant-returns-to-scale and the representative-firm assumptions, the retail price is determined by the marginal cost.

Cost-minimizing demands are homogeneous of degree zero in prices. The marginal cost function is homogeneous of degree one in prices. If α is a positive constant, then:

$$(1)\qquad \mathbf{Q}_w(\mathbf{P}_w, \mathbf{P}_m, \mathbf{Q}_r)\left(= \frac{\partial C(\mathbf{P}_w, \mathbf{P}_m, \mathbf{Q}_r)}{\partial \mathbf{P}_w} \right) = \mathbf{Q}_w(\alpha\mathbf{P}_w, \alpha\mathbf{P}_m, \mathbf{Q}_r)$$

and

(2) $$\alpha \mathbf{P}_r = \frac{\partial C(\mathbf{P}_w, \mathbf{P}_m, \mathbf{Q}_r)}{\partial \mathbf{Q}_r}.$$

Together, (1) and (2) imply that if you invert the wholesale demand and marginal cost functions to solve for the wholesale price and retail quantity, the wholesale price equation will be homogeneous of degree one and the retail quantity equation will be homogeneous of degree zero.

The derived inverse demands are also symmetric in quantities. To prove this, take the total derivatives of (1) and (2) with respect to retail prices, retail quantities, wholesale prices, and wholesale quantities (ignoring for the moment the effects of input prices):

(3) $$\begin{bmatrix} d\mathbf{P}_r \\ d\mathbf{Q}_w \end{bmatrix} = \begin{bmatrix} \frac{\partial^2 C}{\partial \mathbf{Q}_r^2} & \frac{\partial^2 C}{\partial \mathbf{Q}_r \partial \mathbf{P}_w} \\ \frac{\partial^2 C}{\partial \mathbf{P}_w \partial \mathbf{Q}_r} & \frac{\partial^2 C}{\partial \mathbf{P}_w^2} \end{bmatrix} \begin{bmatrix} d\mathbf{Q}_r \\ d\mathbf{P}_w \end{bmatrix}.$$

With separable costs, $\partial^2 C/\partial \mathbf{Q}_r^2$ will be diagonal. If there are joint costs, then $\partial^2 C/\partial \mathbf{Q}_r^2$ has off-diagonal terms. The term $\partial^2 C/\partial \mathbf{Q}_r^2$ must be positive semidefinite; otherwise, the derivative of the cost function with respect to retail meat production will not represent the competitive equilibrium retail price. It will be positive definite if there are decreasing returns to scale, and semidefinite with constant returns to scale. Under the assumption that the cost of retailing one meat is independent of other meats' wholesale prices, the term $\partial^2 C/\partial \mathbf{Q}_r \partial \mathbf{P}_w$ and its transpose are diagonal. Under fixed proportions, $\partial^2 C/\partial \mathbf{Q}_r \partial \mathbf{P}_w$ will be the wholesale meat required for each unit of retail meat produced, which will be independent of prices and production levels. In any case, the diagonals of $\partial^2 C/\partial \mathbf{Q}_r \partial \mathbf{P}_w$ should be positive.

The assumption that the cost of retailing one meat is independent of the other meats' wholesale prices also makes the $\partial^2 C/\partial \mathbf{P}_w^2$ matrix diagonal. If there are variable proportions in the production of retail meat from wholesale meat, the diagonal elements of $\partial^2 C/\partial \mathbf{P}_w^2$ will be negative. Under fixed proportions, $\partial^2 C/\partial \mathbf{P}_w^2$ is a matrix of zeros. (With fixed proportions, the cost-minimizing demand for wholesale input is determined by the retail output and is not sensitive to input prices.)

Equation (3) can be solved for $d\mathbf{Q}_r$ and $d\mathbf{P}_w$ by inverting the matrix on the right-hand side. Because the original matrix is symmetric, its inverse is also symmetric, proving that the effects of wholesale quantities on wholesale prices will be symmetric. Now, the exact effect of wholesale quantities and retail prices on wholesale prices will depend on the cost technology. Inverting (3) and writing out only the solution for $d\mathbf{P}_w$ gives:

(4) $$d\mathbf{P}_w = \left[\left(\frac{\partial^2 C}{\partial \mathbf{P}_w^2} + \frac{\partial^2 C}{\partial \mathbf{P}_w \partial \mathbf{Q}_r} \left[\frac{\partial^2 C}{\partial \mathbf{Q}_r^2} \right]^{-1} \frac{\partial^2 C}{\partial \mathbf{Q}_r \partial \mathbf{P}_w} \right)^{-1} \frac{\partial^2 C}{\partial \mathbf{P}_w \partial \mathbf{Q}_r} \left(\frac{\partial^2 C}{\partial \mathbf{Q}_r^2} \right)^{-1} \right] d\mathbf{P}_r + \left(\frac{\partial^2 C}{\partial \mathbf{P}_w^2} - \frac{\partial^2 C}{\partial \mathbf{P}_w \partial \mathbf{Q}_r} \left[\frac{\partial^2 C}{\partial \mathbf{Q}_r^2} \right]^{-1} \frac{\partial^2 C}{\partial \mathbf{Q}_r \partial \mathbf{P}_w} \right)^{-1} d\mathbf{Q}_w.$$

Equation (4) implies that the wholesale price is symmetric in wholesale quantity changes. Because of the various expected sign constraints on the cost function's derivatives, the matrix multiplying $d\mathbf{P}_w$ should not be positive definite. It can be either zero or negative (semi-) definite.

Mathematically, there is no problem with inverting the system in equation (3), assuming that the matrix of second-order partials on the right-hand side of equation (3) is nonsingular, to yield the system in equation (4). However, an anonymous reviewer pointed out that a consistent economic interpretation of the inversion process requires some care. The system in (3) is based on an individual firm where the wholesale quantity demand function is expressed as a function of wholesale prices, prices of other inputs, and retail output. At the firm level, wholesale prices are treated as exogenous, and so the quantity of the wholesale demand can change without wholesale prices changing, i.e., the supply of wholesale quantities is considered perfectly elastic. However, once the move is made from the individual firm level to a representative firm model of market-level data, the assumption of an exogenous price becomes debatable.

Within a representative firm market-level model, price and quantity are possibly endogenous, and some insight into classifying which is endogenous or exogeneous can be guided by a length-of-run argument. As is well known, as the length of run becomes shorter, the supply of most commodities becomes more inelastic. Because the data that will be used are monthly, it seems reasonable to treat the supply of the wholesale input quantities (fresh meats) as fixed, and therefore the supply as perfectly inelastic. In this case, the representative firm market-level inverse demand represented by equation (4) would uniquely determine price. However, to allow for the possibility that quantity is endogenous, instrumental variables are used to account for the possible endogeneity of wholesale quantity that appears on the right-hand side of equation (4).[1]

If costs are separable, all the submatrices in (4) are diagonal, and we will have the case where the wholesale price of a good depends on its retail price and (perhaps) its wholesale quantity. With joint costs *and* substitution, the wholesale price of any meat may depend on all the retail prices and all the quantities. As noted above, with fixed proportions, $\partial^2 C/\partial \mathbf{P}_w^2$ is zero, so (4) becomes:

$$(5) \qquad d\mathbf{P}_w = \left[\frac{\partial^2 C}{\partial \mathbf{Q}_r \partial \mathbf{P}_w}\right]^{-1} d\mathbf{P}_r - \left(\frac{\partial^2 C}{\partial \mathbf{Q}_r \partial \mathbf{P}_w}\right)^{-1}\left(\frac{\partial^2 C}{\partial \mathbf{Q}_r^2}\right)\left(\frac{\partial^2 C}{\partial \mathbf{P}_w \partial \mathbf{Q}_r}\right)^{-1} d\mathbf{Q}_w .$$

[1] An anonymous reviewer suggested two alternative approaches to the one used here. Use a distance function to derive the inverse demand system in (4), which by duality would yield the same type of specification as (4). Second, use a framework that includes both supply and demand functions. The latter approach has been used by Wohlgenant, and by Brester and Wohlgenant. The main reasons for not pursuing these two approaches are as follows. Regarding the first approach, we were interested in testing several restrictions about behavior that are easily expressed in terms of the cost function, and the mapping between these restrictions on the cost function and the analogous restrictions on the distance function have not to our knowledge been established. Thus such an approach is beyond the scope of this study. Regarding the second approach, again testing the cost function restrictions in terms of market-level supply and demand curves is not a trivial step. Clearly, there are several theoretical aggregation problems that need to be examined when moving from a firm-level model to a market-level model. However, these theoretical issues are beyond the scope of this study, and the instrumentation of the endogenous quantity should correct for any empirical problems these theoretical issues may cause.

In (5) the matrix multiplying $d\mathbf{P}_r$ is now diagonal, so that with joint costs but without substitution, the wholesale price will depend on its own retail price (but not the other retail prices) and all the quantities. The one case that the derived inverse demand rules out is where there are cross-retail price effects but no cross-quantity effects.

The model actually estimated in this analysis is based on differences in logarithms, so it is necessary to convert the symmetry and homogeneity restrictions implied into restrictions on the flexibilities. Suppose that $f_{i,j}$, $g_{i,j}$, and $h_{i,k}$ are the flexibilities of the wholesale price of meat i with respect to the retail price and wholesale quantity of meat j, and the price of input k. The inverse demand for meat i can be written in flexibility form as:

$$(6) \qquad \mathrm{dLog}(p_{w,i}) = \sum_{j=1}^{3} \mathrm{dLog}(p_{r,j}) f_{i,j} + \sum_{j=1}^{3} \mathrm{dLog}(q_{w,j}) g_{i,j} + \sum_{k} \mathrm{dLog}(p_{m,k}) h_{i,k}.$$

If (6) is to be homogeneous of degree one, the following restrictions must be imposed on the retail price and input cost flexibilities:

$$(7) \qquad 1 = \sum_{j=1}^{3} f_{i,j} + \sum_{k} h_{i,k}, \quad \forall\, i.$$

The symmetry conditions on the own-quantity flexibilities (at a particular point) are:

$$(8) \qquad p_{w,i} q_{w,i} g_{i,j} = p_{w,j} q_{w,j} g_{j,i}, \quad \forall\, i, j.$$

Equation (8) is equivalent to (9):

$$(9) \qquad p_{w,i} S_i = p_{w,j} S_j, \quad \forall\, i, j,$$

where

$$S_i = \frac{p_{w,i} q_{w,i}}{\sum_{k=1}^{3} p_{w,k} q_{w,k}}.$$

Equations (7)–(9) are true at any point for any arbitrarily defined technology. Note that the flexibilities associated with a particular technology may vary as input costs and wholesale quantities vary.

If costs are separable, then the cross-retail-price and cross-wholesale-quantity flexibilities will all be zero. Under constant returns to scale in the marketing of all meats, doubling all the wholesale quantities while keeping retail prices and other input costs fixed will leave wholesale prices unchanged. Constant returns to scale would result in the following restriction on the flexibilities:

$$(10) \qquad \sum_{j=i}^{3} g_{i,j} = 0, \quad \forall\, i.$$

Constant returns to scale for each meat and separable costs imply that all the quantity flexibilities are zero.

Adding Dynamics and Asymmetric Price Transmission While Keeping the Long-Run Structure

The data used in this study have monthly observations of prices, quantities, and marketing cost indices. Previous research (as summarized by Schwartz and Willet) tends to show that there is lagged adjustment of retail food prices to wholesale food price changes. Boyd and Brorsen, and Hahn also showed asymmetric price transmission in pork and, in Hahn's case, beef markets. The model will incorporate dynamics using a slight modification of a concept and technique developed by Anderson and Blundell for adding dynamic features to consumer demand systems. Anderson and Blundell start with a fairly general dynamic representation which nests a wide variety of expectation- and adjustment-driven models. Their technique will be modified to handle asymmetric interactions and, what is more important, to eliminate nonlinear restrictions. Anderson and Blundell developed their approach for systems of demand equations. While we estimate a system of demand equations in the current study, the Anderson-Blundell technique and the modification will be demonstrated using a single equation with a simple lag structure to make the discussion clearer.

Anderson and Blundell argue that the restrictions of comparative static microeconomic theory represent a long-run equilibrium position and that dynamics arise from the transition to that equilibrium. Suppose that y_t is the value of an endogenous variable at time t, and that x_t is an exogenous variable. A general dynamic equation linking y to current and lagged x and lagged y can be written:

$$y_t + \gamma y_{t-1} = \beta_0 x_t + \beta_1 x_{t-1}. \tag{11}$$

Anderson and Blundell report that a wide range of expectation-based and adjustment models have forms like (11), especially if one allows for the possibility of longer lags. Assuming that the process in (11) is dynamically stable, the long-run effect of a change in x on y is:

$$\frac{\beta_0 + \beta_1}{1 + \gamma} = \mathrm{B}. \tag{12}$$

Many restrictions on the long-run effect imply complicated nonlinear restrictions on the dynamic coefficients. These problems increase as one adds equations, terms, and cross-equation restrictions. Anderson and Blundell demonstrate that equations like (11) can be manipulated to yield equations similar to (13):

$$\Delta y_t = b_0 \Delta x_t + \Gamma\left(y_{t-1} - \mathrm{B}x_{t-1}\right), \tag{13}$$

where Δ is the difference operator. Now, while (13) is still nonlinear, the B coefficient can be directly estimated, and restricting its value is more straightforward.

In deriving their procedure, Anderson and Blundell note, for instance, that y_t is $\Delta y_t + y_{t-1}$. However, it is also true that y_{t-1} is $y_t - \Delta y_t$. So, (11) can be rewritten as:

$$y_t + \gamma\left(y_t - \Delta y_t\right) = \beta_0 x_t + \beta_1\left(x_t - \Delta x_t\right), \tag{14}$$

which yields

(15) $$y_t - \frac{\gamma}{1+\gamma}\Delta y_t = \frac{\beta_0 + \beta_1}{1+\gamma}x_t + \frac{\beta_1}{1+\gamma}\Delta x_t$$

or

(16) $$y_t + a_1\Delta y_t = \mathrm{B}x_t + b_1\Delta x_t.$$

Equation (16) has no nonlinear restrictions. The major problem with (16) is that it now has two current endogenous variables, y_t and Δy_t. The Anderson and Blundell model can be estimated by least squares techniques, while the modified approaches need to be estimated with simultaneous equation techniques. However, given that retail prices, wholesale prices, and wholesale quantities are all potentially jointly determined, simultaneous equation techniques are appropriate for the model estimated for this study. In fact, much research on price transmission in food markets assumes that retail prices follow wholesale prices or farm prices, so the inverse derived demand model used here reverses the commonly assumed causal flow. (Hahn did find evidence that retail beef and pork prices were simultaneously determined with wholesale prices rather than recursively determined from wholesale prices.)

Boyd and Brorsen, and Hahn used variations on the same basic model to add asymmetric price interactions to their models. Both of these studies distinguished between shorter-run asymmetric price transmission and irreversible responses. The model used here will not incorporate irreversibility, as irreversibility is inconsistent with a stable long-run structure.

Assuming that the values of y and x can be either negative or positive, previous approaches have added asymmetry by dividing the variables into two components, the positive part and the negative part. For example, z_t can be used to make z_t^+ and z_t^- applying the formulas in (17) and (18):

(17) $$z_t^+ = \begin{cases} z_t & \text{if } z_t > +0, \\ 0 & \text{if } z_t < 0, \end{cases}$$

and

(18) $$z_t^- = \begin{cases} 0 & \text{if } z_t > +0, \\ z_t & \text{if } z_t < 0. \end{cases}$$

A general asymmetric version of (11) could be written:

(19) $$y_t^+\gamma_0^+ + y_t^-\gamma_0^- y_{t-1}^+\gamma_1^+ + y_{t-1}^-\gamma_1^- =$$
$$x_t^+\beta_0^+ + x_t^-\beta_0^- x_{t-1}^+\beta_1^+ + x_{t-1}^-\beta_1^-.$$

Equation (19) is an endogenous switching-type equation and is consistent with Hahn's more general model. In order for (19) to be reversible, the following two conditions must hold:

(20) $$\gamma_0^+ + \gamma_1^+ = \gamma_0^- + \gamma_1^-$$

and

(21) $$\beta_0^+ + \beta_1^+ = \beta_0^- + \beta_1^-.$$

Assuming, again, dynamic stability, the long-run effect of a change in x on y is the ratio of the sums of the beta coefficients to the sum of the gamma coefficients. The restrictions in (20) and (21) imply that it does not matter whether one sums the "+" or "−" superscripted coefficients. Using the same procedure followed in (14)–(16), and the restrictions in (20) and (21), (19) can also be written similarly to (16):

$$y_t + a_1^+\Delta y_t^+ + a_1^-\Delta y_t^- = \mathrm{B}x_t + b_1^+\Delta x_t^+ + b_1^-\Delta x_t^-. \tag{22}$$

Like (16), (22) somewhat obscures the effects of lags and asymmetry. However, if, for example, y's reaction to x is symmetric, then b_1^+ and b_1^- will be the same. If y has no lagged response to x, then both b_1^+ and b_1^- will be zero. Equation (22) and its variants allow one to test hypotheses about asymmetry and lag lengths using linear parameter restrictions even though the asymmetric and dynamic effects are nonlinear functions of the parameter estimates.

The Model and Results

Descriptions of the variables used in the model, as well as their sources, are presented in table 1. The data set includes 216 monthly observations that start with January 1979 and end with December 1996. (The first two observations were lost due to differencing and lags.) The pork and beef prices are based on those used by the USDA to calculate price spreads. These prices are based on the assumption that there is a fixed-proportions relationship among farm, wholesale, and retail pork and beef. The USDA reports these pork and beef prices in terms of dollars per pound of retail equivalent. USDA proportions were used to transform the retail and wholesale beef and pork prices into dollars per pound of wholesale equivalent.[2] The chicken prices are wholesale and retail prices of whole birds. The quantity variables for beef and pork are carcass-weight disappearance, which were adjusted to a wholesale-weight basis using the most current USDA carcass-to-wholesale weight conversion factor. [Converting carcass-weight disappearance into wholesale-weight disappearance matters in calculating each meat's share of the wholesale meat dollar, the S_i term defined in equation (9).] Three variables were used as measures of input costs: hourly earnings of food and commercial workers, the producer price index, and the consumer price index. The bottom portion of table 1 also includes a list of the instrumental variables and their sources.

The most general, dynamic, asymmetric, inverse, derived demand equation estimated is given by:

$$\begin{aligned} \mathrm{dln}(p_{w,i,t}) &+ \sum_j \left(c_{i,j}^+\Delta\mathrm{dln}(p_{w,j,t}^+) + c_{i,j}^-\Delta\mathrm{dln}(p_{w,j,t}^-)\right) \\ &= \sum_j \left(f_{i,j}\mathrm{dln}(p_{r,j,t}) + f_{i,j}^+\Delta\mathrm{dln}(p_{r,j,t}^+) + f_{i,j}^-\Delta\mathrm{dln}(p_{r,j,t}^-)\right) \\ &+ \sum_j \left(g_{i,j}\mathrm{dln}(q_{r,j,t}) + g_{i,j}^+\Delta\mathrm{dln}(q_{w,j,t}^+) + g_{i,j}^-\Delta\mathrm{dln}(q_{w,j,t}^-)\right) \\ &+ \sum_k \left(h_{i,k}\mathrm{dln}(p_{m,k,t}) + h_{i,k}^s\Delta\mathrm{dln}(p_{m,k,t})\right) + k_i + e_{i,t}, \end{aligned} \tag{23}$$

[2] Over time, the USDA has changed the proportions that it uses to convert farm beef and pork to wholesale beef and pork to retail beef and pork. However, after each revision, the USDA revises its historical farm, wholesale, and retail prices by using past data and current procedures.

Table 1. Variable Descriptions and Sources

Variables / Description		Sources [a]
Retail Prices:		
Beef	Beef, Choice, Grade 3, retail price	ERS
Pork	Pork, U.S. retail price	ERS
Chicken	Whole fryers	BLS; ERS
Wholesale Prices:		
Beef	Beef, Choice, Grade 3, wholesale value	ERS
Pork	Pork, wholesale value	ERS
Chicken	Broilers: 12-city composite wholesale price, ready-to-cook, delivered	ERS
Wholesale Quantities:		
Beef	Total monthly carcass disappearance	ERS
Pork	Total monthly carcass disappearance	ERS
Chicken	Total monthly ready-to-cook disappearance	ERS
Other Input Costs:		
Consumer Price Index (CPI)		BLS
Producer Price Index (PPI)		BLS
Average hourly earnings of workers in food and related industries		BLS
Instrumental Variables (other than input costs):		
Monthly dummies		
Corn price: #2 Yellow, Central Illinois		ERS
Soybean meal price: 48% Solvent, Central Illinois		ERS
Personal consumption expenditures, per capita		BLS
Prices received by farmers, alfalfa hay		ERS
CPI for food		BLS
CPI for cereals and bakery		BLS
CPI for dairy products		BLS
CPI for fruits and vegetables		BLS
CPI for other food		BLS
CPI for food away from home		BLS

[a] ERS = Economic Research Service (of the USDA); BLS = Bureau of Labor Statistics (of the U.S. Department of Labor).

where $d\ln(p_{w,i,t})$ and $d\ln(p_{r,i,t})$ are the change in the logarithm of the wholesale and retail prices, respectively, of meat i; $d\ln(q_{w,i,t})$ is the change in the logarithm of the wholesale quantity of meat i; $d\ln(p_{m,k,t})$ is the change in the logarithm of the price of input k; and $e_{i,t}$ is a random error term. Equation (23) also has asymmetric terms for the changes in the retail and wholesale price and wholesale quantities. Since price declines for these input cost measures are rare, the input price terms are not divided into increases and decreases; that is, it is assumed that input prices have symmetric short-run effects on the inverse demand.

Table 2. R^2s for Endogenous Variables from Stage 1 (in percent)

Meat	Variable	Change in Log of:	Positive Change in Log of:	Negative Change in Log of:
Beef	Wholesale price	30.973	22.836	31.443
	Retail price	63.411	50.204	56.552
	Wholesale quantity	99.574	97.437	97.829
Pork	Wholesale price	39.182	35.243	30.265
	Retail price	65.063	59.701	47.915
	Wholesale quantity	79.991	76.539	67.099
Chicken	Wholesale price	43.123	38.488	36.289
	Retail price	49.553	51.320	38.468
	Wholesale quantity	76.121	64.884	72.909

The $f_{i,j}$, $g_{i,j}$, and $h_{i,k}$ terms are flexibility coefficients as defined in (6). When (23) was estimated, the homogeneity conditions in (7) were imposed on the flexibilities. As (8) and (9) show, the long-run cross-quantity symmetry conditions depend on the levels of the expenditure on meats. Since these vary over the sample period, the symmetry conditions were imposed at the average values of the S_i terms as defined in (9). Equation (23) is a local approximation to the meat-retailing technology.

The c coefficients on the left-hand side of (23) allow for lagged and asymmetric adjustment in the wholesale price. If the cross-effects, $c^+_{i,j}$ and $c^-_{i,j}$ when i and j are different, are all zero, then (23) is basically an asymmetric version of a partial adjustment model. Adding nonzero cross-c terms produces a more complex, error-correction-type adjustment process. Dynamics and asymmetry also enter into (23) through the coefficients on the right-hand side with superscripts: $f^+_{i,j}$, $f^-_{i,j}$, $g^+_{i,j}$, $g^-_{i,j}$, and $h^s_{i,k}$. A variable on either side of the equation has an asymmetric effect if its "+" coefficient is different from its "−" coefficient. It has a dynamic effect if either or both of the coefficients with "−" or "+" superscripts are nonzero.

Because of the potential simultaneity among the retail prices, wholesale prices, and wholesale quantities, the model in (23) was estimated by using instrumental variable techniques, a version of nonlinear three-stage least squares. The model was evaluated using the asymptotic covariance matrix of the coefficients—that is, using chi-square and Z-tests on the coefficients. This evaluation criterion was selected for two basic reasons. First, the coefficients themselves determine much of the interesting behavior of the model. Nonzero cross-quantity and/or cross-retail price effects are evidence of joint costs in meat retailing. The second reason is that model-fit criteria, such as the likelihood ratio, are not appropriate in this context. The three-equation system specified by (23) is only part of a total system linking wholesale prices, quantities, and retail prices. Complete specification of the entire system would require at least six more equations: three for wholesale-level meat supplies and three reduced-form equations for the retail prices.

Thirty-eight instrumental variables were used in the first stage: the 12 monthly dummies, and the change in the logarithm and the square of the change in the logarithm of the other 13. The squared terms were used because, under the assumption of asymmetry, (23) is actually a nonlinear model. Table 2 shows how well the instruments

Table 3. Results of Hypothesis Tests for the Most General Model

Hypothesis Tests	χ^2 Statistic	Degrees of Freedom	Significance Level (%)
Long-Run Quantity Effect Tests:			
All quantities	28.935	6	0.0
Own-quantities	12.842	3	0.5
Cross-quantities	23.548	3	0.0
Constant returns to scale (CRTS)	1.177	3	75.8
Long-Run Retail Price Effect Tests:			
All retail prices	125.338	9	0.0
Own-price	82.491	3	0.0
Cross-price	7.065	6	31.5
Testing for Asymmetric Responses:			
Imposing symmetry on the wholesale price terms in all equations	2.316	9	98.5
▸ Own-price	0.433	3	93.3
▸ Cross-price	1.382	6	96.7
Imposing symmetry on the retail price terms in all equations	3.324	9	95.0
▸ Own-price	0.409	3	93.8
▸ Cross-price	2.857	6	82.7
Imposing symmetry on the wholesale quantity terms in all equations	7.488	9	58.6
▸ Own-quantity	0.975	3	80.7
▸ Cross-quantity	2.838	6	82.9
Imposing symmetry on the model	13.342	27	98.7

fit the endogenous variables in the first stage of the estimation. The R^2 statistics are quite good for log-differenced data, and the first stage fits the asymmetric endogenous variables about as well as the ordinary endogenous variables.

Table 3 lists some of the results of hypothesis tests on the most general model. Note that long-run quantity effects are generally significant, as are the cross-quantity effects specifically. The hypothesis of constant returns to scale cannot be rejected. However, the cross-retail effects are not, as a group, significant. The results from the estimates of (23) are consistent with joint costs in the retailing of meats, but with fixed proportions in producing retail meat from wholesale meat.

The model based on (23) has 87 free coefficients given the homogeneity and symmetry restrictions, and its inability to reject fixed proportions might be the result of inefficient estimates. For instance, hypothesis tests in the lower section of table 3 cast doubt on the importance of asymmetry in price and quantity interactions. Imposing more restrictions could decrease the standard error of the remaining coefficients, so hypothesis tests were used to continually restrict the model to see if the cross-retail effects would become significant.

Because the hypothesis of symmetric price transmission could not be rejected, a second, symmetric model was estimated. This model was tested for dynamic effects. The only lagged coefficients that were statistically significant were the own-price lags for the

Table 4. Results of Hypothesis Tests for Sequentially Restricted Models

Hypothesis Tests	χ^2 Statistic	Degrees of Freedom	Significance Level (%)
Testing Lags and Intercepts on the Symmetric Model:			
Retail price lags	10.799	9	29.0
▸ Own-effects	5.573	3	13.4
▸ Cross-effects	5.215	6	51.7
Wholesale price lags	101.188	9	0.0
▸ Own-effects	75.342	3	0.0
▸ Cross-effects	6.721	6	34.7
Quantity lags	10.855	9	28.6
▸ Own-effects	2.204	3	53.1
▸ Cross-effects	10.213	6	11.6
Input cost lags	7.056	9	63.1
Intercept tests	0.948	3	81.4
Simultaneous test that retail lags, quantity lags, input cost lags, cross-wholesale lags, and intercepts are all zero	37.772	36	38.8
Testing Input Cost Terms in Model with Restricted Lags and No Intercepts:			
All cost terms in all equations	14.764	9	9.8
CPI terms only	7.382	3	6.1
PPI terms only	6.551	3	8.8
Wage terms only	4.431	3	21.9
CPI and PPI	9.938	6	12.7
CPI and wages	14.194	6	2.8
PPI and wages	10.752	6	9.6

wholesale price. The other lags and intercepts were not significant, either when tested by themselves or when tested simultaneously (table 4). The third model estimated dropped the intercepts and all but the own-price wholesale lags. Testing in the fourth phase led to the dropping of the producer price index (PPI) term for all three meats (table 4).

The fourth model estimated was symmetric, with lags only on the own wholesale price, and without PPI terms or intercepts. Table 5 shows what happens when the retail price and wholesale quantity restrictions were tested on the fourth, more restricted model. Again, the cross-retail price effects were found to be statistically nonsignificant, while the own- and cross-wholesale quantities were found to be significant. And again, the hypothesis of constant returns to scale could not be rejected.

Table 5 also shows tests of USDA proportions. The data on wholesale prices and retail prices for beef and pork are those used by the USDA to calculate price spreads. These price series are constructed assuming fixed proportions, and the wholesale prices are transformed so that a pound of retail meat requires one pound of its wholesale equivalent. (As noted above, the wholesale and retail beef and pork prices were transformed to a wholesale-equivalent basis using the USDA's fixed proportions.) Further, the wholesale and retail prices used in this study are for whole birds, so one might expect to find

Table 5. Results of Retail Price and Wholesale Quantity Tests on Restricted Model

Hypothesis Tests	χ^2 Statistic	Degrees of Freedom	Significance Level (%)
Long-Run Quantity Effect Tests:			
All quantities	26.498	6	0.0
Own-quantities	19.284	3	0.0
Cross-quantities	22.983	3	0.0
Constant returns to scale (CRTS)	0.417	3	93.7
Long-Run Retail Price Effect Tests:			
All retail prices	155.067	9	0.0
Own-price	111.516	3	0.0
Cross-price	6.381	6	38.2
Testing that Price Transmission Is Consistent with USDA Proportions and the Average Retail/Wholesale Price Ratio:			
For all three meats simultaneously	19.890	3	0.0
For beef	0.318	1	57.3
For pork	11.412	1	0.1
For chicken	5.715	1	1.7
Joint test of no cross-retail, CRTS, and USDA proportions for beef	9.324	10	50.2

a one-to-one relationship between the retail and wholesale prices for chicken also. With fixed proportions, the relationship between the retail price and the wholesale price ought to be:

$$dp_{w,i} = dp_{r,i}B_i, \tag{24}$$

where B_i is a positive constant and is the pounds of retail product produced by a pound of wholesale product. Equation (24) can be expressed as an elasticity:

$$\frac{\partial \log(p_{w,i})}{\partial \log(p_{r,i})} = \frac{p_{r,i}}{p_{w,i}} B_i. \tag{25}$$

If one pound of wholesale meat produces one pound of retail meat, then B_i is one, and the flexibility of price transmission from retail to wholesale is the ratio of the retail price to the wholesale price. Table 5 shows what happens when the estimated flexibility is tested against the average retail-to-wholesale price ratio. When tested as a group, all three are significant at the 5% level. When tested individually, the pork and chicken retail-to-wholesale prices are significantly different from the average retail-wholesale price ratio, while beef's is not.

The nonrejected restrictions were combined to make a fifth version of the model, one with fixed proportions and constant returns to scale, and with USDA proportions imposed on beef's retail price effect. The estimates for this model can be found in table 6.

Table 6. Coefficient Estimates of the Most Restricted Model

Coefficient	Equation		
	Beef	Pork	Chicken
Double-differenced wholesale price	-0.1849	-0.2393	-0.2769
	(0.0532)	(0.0419)	(0.0322)
Own retail price effect	1.5352	1.1880	1.1304
	—[a]	(0.1264)	(0.1411)
Implied ratio between wholesale input and wholesale weight adjusted retail output (at average retail / wholesale price ratio)	1[a]	0.6906	0.7222
Beef quantity flexibility	-0.1450	0.1319	0.3086
	(0.0277)	(0.0327)	(0.0753)
Pork quantity flexibility	0.0594	-0.0621	-0.1135
	(0.0209)	(0.0213)	(0.0704)
Chicken quantity flexibility	0.0855	-0.0698	-0.1951
	(0.0148)	(0.0275)	(0.0346)
CPI effect	-0.8040	-0.2520	0.0395
	(0.2221)	(0.2815)	(0.3038)
Wage effect	0.2689	0.0641	-0.1699
	(0.2221)	(0.2381)	(0.2739)

Note: Numbers in parentheses are standard errors.
[a] The beef own-retail price coefficient is restricted to be consistent with USDA price spread proportions.

The coefficients for the double-differenced, own wholesale price are all negative. After all the restrictions are imposed, the right-hand sides of the demand equations are basically static demand functions. The c coefficients make the model a partial adjustment-type model. If the demand equation is seen as determining the wholesale price, then the roots of the dynamic equations are all negative, meaning that the wholesale price tends to overshoot its equilibrium value in the short run. If the demand equation is inverted to find the retail price, then the negative c coefficients imply that the retail price reacts with a lag to wholesale price changes. All of the c coefficients are around -0.2, so inverting and solving for the retail price implies that approximately 80% of the change in the wholesale price is transmitted to the retail price in the first month, with the rest of the change affecting the retail price in the next month.

The values of the retail-wholesale price transmission flexibility for pork and chicken are smaller than their respective average retail/wholesale price ratios. Equation (25) can be solved for the retail/wholesale quantity ratio, and table 6 shows the quantity ratio implied by the price transmission flexibility and the average price ratio. For pork and chicken, the ratio is less than one, which would be consistent with the USDA overestimating the amount of retail pork and chicken produced by wholesale pork and chicken.

The own-quantity flexibilities are negative, and the overall quantity flexibilities are negative semidefinite, and therefore consistent with microeconomic theory. In order to have constant-returns-to-scale and negative-semidefinite demand effects, some or all of the cross-quantity effects must be positive. Those for beef are positive—that is, increasing beef quantities tends to raise the wholesale price of other meats and, because of symmetry, vice versa. Pork's and chicken's cross-quantity effects are negative, so increasing pork quantities decreases chicken prices and vice versa.

Implications and Conclusions

In the first section of this article, we identified two questions that this investigation specifically intended to address about the technology of meat retailing. The answers to these questions are: (1) yes, meat retailing does appear to be a joint cost activity, and (2) yes, meat-retailing technology does appear to require fixed proportions between meat input and meat output.

One problem shared by this study and other works on retail meat technology is that the tests used for the models are indirect; i.e., neither this nor any of the works cited uses a direct estimate of retail meat output. Although direct observation of wholesale meat output from farm animal input has not allowed economists to come up with a consistent strategy for substitution at that phase of the marketing chain, direct tests on retail technology would be better, but these would require different data—specifically data on wholesale food input matched with retail food output.

It would be worthwhile to try these indirect tests of retail technology with other functional forms—some that might be more flexible or that have global, rather than local, properties. It might also be useful to examine margins and technology for other food products, or perhaps even the entire range of products simultaneously. In any case, based on these empirical results, economists need to put more thought into modeling the technologies of food processing and retailing.

[*Received July 1999; final revision received February 2000.*]

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