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## A markup over average cost pricing rule for meat and poultry in the United States

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### ABSTRACT

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This paper tests the hypothesis that meat and poultry wholesalers choose their inventory levels together with wholesale price so as to maximize profit made over the sales time of their stock. The behavioral assumption predicts that markup over average cost will match the inverse of the price elasticity of the sales time of inventory. Price elasticity of inventory sales time is estimated for beef, pork and poultry accounting for the simultaneity between these pricing decisions by adopting a systems approach. The estimated range for the inverse of these elasticities includes all the markups applied over the sample range of the time series.

### INTRODUCTION

The characteristics of the meat and poultry industries in the United States are suggestive of the importance of planning the production process to minimize costs. The poultry industry is concentrated and vertically integrated. Companies like Tyson or Foster Farms deal with a manufacturing process that runs from the fertilized egg to the dressed hen. Thus chicks go to the growing houses in cost-efficient batches, and the size of these batches determines the cost-efficient output flow for the dressed chicken. In the beef industry, economies of scale in the slaughter/processing phase are sizable, and there are costs associated to producing below capacity. Commer (1991) estimates that per-unit variable costs in-

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crease by approximately \$1 per head for each 100 000 head below capacity. Commer's figures suggest that a medium-sized slaughter plant with a capacity of 500 000 head per week, operated at 80% capacity, would see its variable cost of producing 400 000 carcasses increase by \$400 000 a week. Economies of scale have motivated a decline in the number of facilities for the slaughter of fed cattle relative to cattle production. But to realize these economies producers must regulate output to avoid producing below full capacity. From an economic viewpoint, facts such as these suggest that the output decisions made by meat and poultry producers are not adequately described by the standard Neoclassical model. Indeed, and in the absence of inventories, this model would have producers choose a level of output and selling price to maximize profit flow at each instant. Thus output flow must be regulated in a continuous fashion, and the issue of cost-efficient planning of production is left unaddressed.

The Neoclassical model of the firm allows, of course, for the holding of inventories. If inventories are conceived of as providing a buffer between demand and production, the theory accounts for cost-efficient regulation of output while meeting the requirements of instantaneous profit maximization. But the evidence for production smoothing inventory behavior is not convincing. As shown by Feldstein and Auerbach (1976) and emphasized by Blinder (1981, 1986), the empirical estimates obtained from a typical production smoothing inventory equation partly contradict the theory from which they are derived. Inventory holding on the part of firms can, however, be interpreted in a different manner. Rather than have inventory provide a buffer between supply and demand, inventory can be conceived of as the symptom of cost-efficient production. In fact, Commer (1991) points out the coincidence of increased cow-calf inventories and the reduced number (and therefore increased capacity) of the facilities for the slaughter of fed cattle. From the viewpoint of the modeling of pricing decisions, this outlook on output and inventory suggests that firms associate a selling price to levels of output that will take some time to sell. But the time it will take to sell that output varies with the price chosen. Given a level of inventory, then, the chosen selling price will determine the time frame over which revenues will be collected against the cost of these goods. The pricing implications of adopting the myopic goal of maximizing average profit made over the sales time of inventory have been examined in Langlois (1989a, b). Maximizing average per-unit-time profit yields a markup over average cost pricing formula which is compatible with the observed pricing practices of the automobile industry in the United States. In this paper, the same model is shown to adequately describe pricing practices in the meat and poultry industries in the United States. This paper's contribution is, therefore, empirical. For the reader's convenience,

however, the theoretical model is described and includes detailed exposition when the issue is of particular relevance to the modeling of meat and poultry wholesale.

Agricultural economists frequently refer to markup over average cost as a pricing rule in the food industry. Wohlgenant (1985) assumes quadratic inventory costs and the maximization of a discounted profit stream to derive a markup pricing rule which is tested using data on the monthly wholesale-retail price spread for beef. Heien (1980) studies disequilibrium adjustments in food prices in a context where "central is the notion that increases in wholesale prices are transmitted to the retail level via markup type pricing behavior." Gardner (1975) investigates the determinants of retail markup over wholesale prices assuming market clearing at all levels of trade. The model presented in this paper follows this tradition, and that of authors such as Nordhaus and Godley (1972) or Sylos-Labini (1962) in that a markup over average cost pricing rule is developed. However, the pricing rule this model generates is myopic since it is based on expected selling time of current inventory. The profit maximizing markup derived here matches the inverse of the price elasticity of the inventory-to-sales ratio. Thus pricing is seen to emerge from an observation of the speed at which inventories turn over, a statistic that real-world firms surely watch.

The first part of this paper presents the model. The second section is empirical. Data on inventory, price and wholesale markup for meat and poultry is used to test the pricing rule of Section 1. Estimation focuses on pricing of beef, pork and poultry and accounts for the simultaneity between these pricing decisions by adopting a systems approach.

## 1. THE MODEL

The pricing rule of thumb I develop can be derived with reference to the standard one-period monopoly profit maximizing model. The textbook monopolist maximizes profit  $\pi(p)$  defined as:

$$\pi(p) = pq(p) - C(q(p)) - f$$

where  $q(p)$  is demand,  $C(q(p))$  is variable cost, and  $f$  is fixed cost. Profit thus defined is understood as profit made within some time interval in which both demand and costs are well defined. In continuous time, flow demand must therefore be confronted to an instantaneous average cost function, and, in the absence of inventories, output and costs must be varied in a continuous manner to accommodate shifts in flow demand. As mentioned above, the complexities of the manufacturing process may not allow continuous regulation of the flow of output. Modern integrated poultry producers must coordinate many functions to achieve cost-effective

production, and batch production is required at some stages of input transformation. For the geographically concentrated meat producers, the production process must be planned to ensure efficient use of capacity. This applies to slaughter facilities but also to the transportation of the processed beef since the centralized carcass cutters must not let their refrigerated trucks travel half empty. In other words, costs are meaningfully defined over levels of output  $Q$  that will take many instants to sell. If  $q(p, \tau)$  is flow demand of date  $\tau$  and price  $p$ , then  $Q$  may take  $t$  periods to sell, where  $t$  solves:

$$\int_0^t q(p, \tau) d\tau = Q$$

If this is the case, then the cost of output  $Q$  must be set against revenues received over some period  $t$  to define a profit function that the decision maker can optimize. That profit can be written:

$$\pi(p, Q) = \int_0^{t(p, Q)} pq(p, \tau) d\tau - C(Q) - f t(p, Q)$$

where  $t(p, Q)$  is the time it will take to sell output  $Q$  at price  $p$ . This approach highlights the following tradeoff. A higher price will generate higher total revenue from the sale of an output level  $Q$ , but it will take longer for the sale to be realized. This suggests defining the objective function as the average per-unit-time profit made over the sales time of output  $Q$  or:

$$\begin{aligned} \pi(p, Q) &= \frac{\int_0^{t(p, Q)} pq(p, \tau) d\tau - C(Q)}{t(p, Q)} - f \\ \pi(p, Q) &= \frac{p \int_0^{t(p, Q)} q(p, \tau) d\tau - C(Q)}{t(p, Q)} - f \\ \pi(p, Q) &= \frac{pQ - C(Q)}{t(p, Q)} - f \end{aligned} \tag{1}$$

This approach to profit maximization is of interest for the economic intuition it provides and for the pricing rule it suggests. Before these aspects are developed, however, the limitations of this formulation must be acknowledged. In the writing of (1), I assume price is held constant throughout period  $[0, t]$  and no discounting is considered within that period. In other words, I am treating the endogenously defined period  $[0, t]$  as a traditional Neoclassical ‘unit period’. Moreover, this monopolist

is myopic. Generalization of this approach to a discounted oligopoly supgame framework requires the definition of each players strategy as the choice of inventory, inventory to sales ratios and prices through time. This is beyond the scope of this paper. However, as indicated in Appendix I, the pricing rule derived for the monopolist remains valid if oligopolists choose single Nash Equilibrium prices for their chosen levels of inventory.

The approach I am presenting requires interpretation of quantity  $Q$ .  $Q$  emerges from the recognition that production must be planned in advance to be cost-effective. Thus, the firm I describe either holds inventories or produces on order since the simultaneous decision and implementation of a level of production within the instant is a costly alternative to the regulation of output made possible by advance planning. Meat and poultry wholesalers hold inventory, and in so doing they provide themselves with the time it will take to sell current inventories to plan and produce the stock that will be held once these are sold.  $Q$  is therefore interpreted as the firm's target inventory, while  $C(Q)$  represents the cost of goods in inventory and  $t(p, Q)$  stands for the inventory-to-sales ratio associated to the selling of stock  $Q$  at price  $p$ .

Turning now to the economic intuition and the pricing implications of this approach, first note that the per-unit-time profit maximization problem:

$$\max_{p, Q} \pi(p, Q) = \frac{pQ - C(Q)}{t(p, Q)} - f$$

suggests a novel representation of demand. Instead of viewing demand as a relationship between price and quantity within a fixed time period, one can consider the time it takes to sell a given level of output  $Q$  at all possible prices. This relationship between the sales time  $t$  of an output level  $Q$ , and price  $p$  will be referred to as the sales lag function for quantity  $Q$ . Thus in the space  $p, Q$  demand is represented by a family of functions indexed by

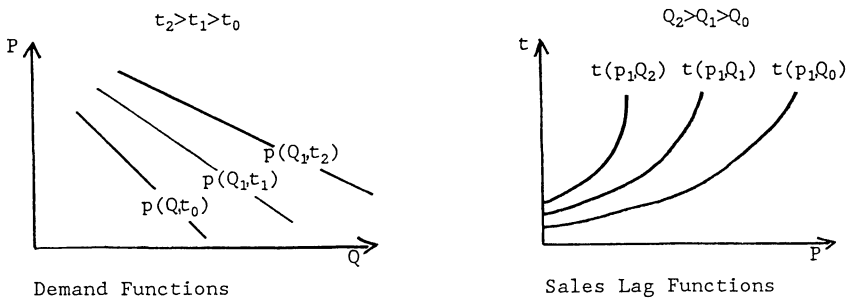


Fig. 1.

$t$ , and in the space  $p, t$  it takes the form of a family of sales lag functions indexed by  $Q$  (see Fig. 1).

As shown in Langlois (1989a, b), explicit per-unit-time profit maximization is also of interest for the pricing formula it yields. Consider the objective function written as a function of  $p$  and  $Q$ :

$$\max_{p, Q} \pi(p, Q) = \frac{pQ - C(Q)}{t(p, Q)} - f$$

Solving for the first-order condition  $\partial\pi/\partial p = 0$  yields a formula for optimal markup over the average cost of goods sold AC:

$$\frac{p - AC}{p} = \frac{1}{\varepsilon(p, Q)} \quad (2)$$

where  $\varepsilon = (\partial t/\partial p)(p/t)$  is the percentage change in sales time resulting from a 1% change in price. If per-unit-time profit is expressed as a function of  $p$  and  $t$  (or  $Q$  and  $t$ ) then the first-order conditions that hold  $t$  constant will yield the familiar markup over marginal cost formula. The objective function reads:

$$\text{Max}_{p, t} \pi(p, t) = \frac{pQ(p, t) - C(Q(p, t))}{t} - f$$

and the first-order condition  $\partial\pi/\partial p = 0$  yields the markup over marginal cost formula:

$$\frac{p - MC}{p} = \frac{1}{|\eta(p, t)|} \quad (3)$$

where  $\eta$  is price elasticity of demand defined on the demand function indexed by  $t$ .

The empirical tests to which we now turn make use of the markup over average cost pricing formula (2) derived above. The reasons for this choice are both theoretical and empirical. Wholesaler behavior is observed through recorded price, inventory levels and sales. From a theoretical and empirical viewpoint, variable  $Q$  has been fixed before price affects sales. Given  $Q$ , wholesalers will do better by allowing sales time to accommodate a higher selling price, than by constraining sales time of its inventory. Symbolically, wholesalers' pricing decision involves choice of  $t$  in order to achieve:

$$\text{Max}_{p, t} \pi(p, t) \quad \text{given } Q$$

A binding sales time constraint  $t = t_0$  would lead to lower profits, and would only be appropriate if wholesalers were overstocked and constrained by product freshness considerations. Thus, once wholesalers hold inven-

tory, the markup over average cost pricing rule (2) derived above is the profit maximizing markup. This does not mean, however, that markup over marginal cost pricing rule (3) does not hold. Indeed, if inventory levels are chosen optimally, their selling time can be constrained to match the inventory sales time resulting from pricing according to rule (2), and profit maximizing price derived from rule (3) would match that chosen according to rule (2). Testing for this would require evaluation of marginal costs for meat and poultry, and the estimation of the price elasticity of demand for the demand curves indexed by observed inventory-to-sales ratios. Thus pricing rule (2) does not exclude pricing rule (3), but rule (2) accounts for the observed choosing by wholesalers of a level of output inventory.

## 2. WHOLESALE INVENTORY AND MARKUP FOR MEAT AND POULTRY: TEST OF A PRICING RULE

### 2.1 Methodology and data requirements

#### 2.1.1 Methodology

The markup over average cost pricing rule  $(p - AC)/p = 1/\varepsilon$  involves an elasticity which is measured along the sales lag function for inventory  $Q$ . By estimating the parameters of the sales lag function for meat and poultry, elasticity  $\varepsilon$  can be measured, and its inverse compared to the markups that are actually applied, at the wholesale level, to direct costs.

Assume the inverse sales lag function for the wholesale inventory of meat and poultry can be expressed as a multiplicative function. The system of inverse sales lag functions to be estimated is then written:

$$\begin{aligned} P_b &= At_b^{a_0} Q_b^{a_1} \\ P_p &= Bt_p^{b_0} Q_p^{b_1} \\ P_c &= Ct_c^{c_0} Q_c^{c_1} \end{aligned} \tag{4}$$

where  $p$ ,  $t$  and  $Q$  represent price, inventory-to-sales ratio and inventory, while subscripts b, p and c refer to beef, pork and poultry, respectively. There are two sources of dependence between the three inverse sales lag functions:

- The inventory-to-sales ratios for each product depend on all prices as well as disposable income. Estimation must therefore account for the simultaneity between own price and inventory-to-sales ratios.
- The overall market for meat is a common source of variation for each of the three inverse sales lag functions. Consequently, residuals obtained from single equation estimation techniques are likely to be correlated.



This will be accounted for by applying the appropriate systems estimation techniques.

The econometric model chosen for each meat's sales lag function must account for the dependence of each item's sales on the price charged for the other two. Consider the inverse sales lag function for beef inventory:

$$P_b = At_b^{a_0} Q_b^{a_1} \quad (5)$$

where  $P_b$  is the price of beef, and  $t_b$  is the time it will take to sell inventory  $Q_b$  of beef, i.e.

$$t_b = \frac{Q_b}{q_b}$$

where  $q_b$  is flow demand for beef;  $q_b$  will be affected by the price of beef substitutes as well as consumer income, and can be written:

$$q_b = DP_b^{\alpha_0} P_c^{\alpha_1} P_p^{\alpha_2} y^{\alpha_3}$$

where  $P_c$  is the price of chicken,  $P_p$  is the price of pork, and  $y$  some concept of disposable income. It follows that:

$$t_b = D^{-1} Q_b P_b^{-\alpha_0} P_c^{-\alpha_1} P_p^{-\alpha_2} y^{-\alpha_3} \quad (6)$$

Replacing  $P_b$  in (6) by its expression in terms of  $t_b$  and  $Q_b$  in (5) yields:

$$t_b = K Q_b^{1-a_1\alpha_0} t_b^{-a_0\alpha_0} P_p^{-\alpha_2} y^{-\alpha_3}$$

or

$$t_b^{1+a_0\alpha_0} = K Q_b^{1-a_1\alpha_0} P_c^{-\alpha_1} P_p^{-\alpha_2} y^{-\alpha_3}$$

where  $K = D^{-1} A^{-a_0}$ . As long as  $1 + a_0\alpha_0$  is strictly positive,  $t_b$  can be expressed as a function of  $Q_b$ ,  $P_c$ ,  $P_p$  and  $y$  which are exogenous relative to equation (5).  $\alpha_0$  is the price elasticity of demand for beef and  $a_0$  is predicted beef markup over average cost.  $1 + a_0\alpha_0$  will be strictly positive as long as the product of beef price elasticity of demand and beef markup over average cost falls short of 1 in absolute value. Symmetrically,  $t_c$  and  $t_p$ , the sales time of chicken and poultry inventories, can be expressed as functions of variables exogenous to each product's inverse sales lag functions if the product price elasticity of demand times markup over average cost stays below 1 in absolute value. The empirical evidence suggests that this is a valid assumption in all cases.

Price elasticities for beef, pork and poultry have been estimated by many authors. Smallwood, Haidacher and Blaylock (1989) review a collection of estimates. Most authors working with time series report beef, pork and poultry price elasticities that are below 1 in absolute value [see, for example, Chavas (1982), Heien (1982) or Huang (1986)], with elasticities

estimated using monthly data lower in absolute value than those revealed by quarterly or annual data (Haidacher et al., 1982). Elasticity estimates for short time series yield higher absolute values. Within the period 1960 to 1980, the highest absolute value estimate is reported to be 2.1 for broilers in sub-period 1970–1979 by Cornwell and Sorenson (1986). Markups over average cost for pork, beef and poultry range from 0.042, to 0.169. In conclusion, multiplying price elasticity of demand by markup over average cost yields a number less than 1 in absolute value in all cases.

Returning to equation (5), the sales lag function for beef can be estimated by replacing  $t_b$  by the instrument  $\hat{t}_b$  constructed by regressing  $t_b$  against the exogenous variables  $Q_b$ ,  $P_c$ ,  $P_b$  and  $y$ . It follows that:

$$P_b = A\hat{t}_b^{a_0}Q_b^{a_1}$$

$\hat{t}_b$  is purged of its dependence on  $P_b$  and accounts for the dependence of  $P_b$  on the price of pork and chicken. Inverse sales lag functions are constructed similarly for chicken and pork to define a three-equation meat demand system:

$$P_b = A\hat{t}_b^{a_0}Q_b^{a_1}$$

$$P_p = B\hat{t}_p^{b_0}Q_p^{b_1} \quad (7)$$

$$P_c = C\hat{t}_c^{c_0}Q_c^{c_1}$$

Coefficients  $a_0$ ,  $b_0$  and  $c_0$  measure the inverse of elasticity  $\varepsilon$  for beef, pork, and poultry. Estimation methodology for demand system (7) is described in Section 2.2 below.

### 2.1.2 Data requirements

Monthly time series for price, inventory-to-sales ratios, inventory, per-capita disposable income and markup over average cost for each commodity would make up the ideal data set. The first four are available with varying degrees of accuracy, depending on the commodity in the Surveys of Current Business. The adjustments made to Survey of Current Business series are described in Appendix II. For markups, however, the source is the Census of Manufactures and the Annual Supplements to the Census, so that these figures are, at best, yearly. For poultry, markup over the cost of materials and production workers at the wholesale level are available yearly. For beef and pork, these data are available at census years only. Markups for a beef–veal–lamb–pork aggregate that we will refer to as meat are available yearly. This information was used to construct a yearly series for beef and pork markups by extrapolating the relationship of beef and pork markups to total meat markups. A detailed account of this computation is given in the Appendix.

## 2.2 *Econometric evidence*

Iterative three-stage least squares was used to estimate the coefficients of the three equation meat inverse sales lag function system (7).

Monthly data running from January 1960 to December 1980 were used to estimate the system. Each product's inverse sales lag function was estimated by regressing the logarithm of price (LNBPRICE for beef, LNPRICE for pork, LNCPRICE for poultry) against a time trend, an instrument for the logarithm of inventory sales time (LNBTIME for beef, LNPTIME for pork, LNCTIME for poultry), and the logarithm of average of beginning and end period inventory (LNPINV for pork, LNCINV for poultry, LNBINV for beef). Seasonal dummies were retained if they were significant at the 5% level. Correction for serial correlation was made for all equations assuming first-order autocorrelation of error terms. Thus, price is modelled to respond to wholesaler expectations of sales time of inventory (beginning period inventory divided by last period's sales) as well as expected level of inventory for the period (average of beginning and end period inventory).

To generate instrumental variables for inventory sales time, LNBTIME, LNPTIME and LNCTIME were regressed against the exogenous variables of the sales lag function, logarithms of substitute prices, the logarithm of per-capita disposable income (LNPCAPDI), seasonal dummies (S1 to S11 are dummies for January to November) and a dummy variable to differentiate the last five years of data from the first fifteen (SHIFT75).

Seasonal dummies were included as instruments if they were found significant in a least square regression of the logarithms of the inventory-to-sales ratios for each product against the exogenous variables just listed. The inclusion of SHIFT75 was motivated by the documented shift in consumer tastes and preferences for meat after 1975 (see, for example, Thurman, 1989). However, this dummy variable was not significant in least square regressions of LNBTIME, LNPTIME, or LNCTIME against the relevant exogenous variables, so system coefficient estimates were derived including and excluding SHIFT75 from the instrument list.

Table 1 reports system estimation results, SHIFT75 being included in the instrument list. All coefficients have the expected sign: an increase in sales time of inventory is associated to a price rise, and a rise in volume inventory requires a price drop for sales time to remain constant. All coefficients are significant at the 5% level. The exclusion of SHIFT75 from the instrument list had a negligible impact on coefficient estimates. This indicates that producers adjust inventory levels to shifts in sales volume. Thus, changes in consumer tastes and preferences that show up as a shift in the time series for sales of meat products do not affect inventory-to-sales time series.

TABLE 1

Inverse sales lag function estimates for meat and poultry

BEEF: Dependent variable LNBPRICE

*Instrument list:* C, TREND, LNBINV, LNPRICE, LNCPRICE, LNPCAPDI, SHIFT75, S1, S2, S3, S4, S5, S6, S7, S8, S9, S11

Independent variables	Coefficient	T-statistic
C	4.270	12.83
TREND	0.004	10.97
LNBTIME	0.098	3.31
LNBINV	-0.134	-2.39
S1	0.018	2.61
S2	0.019	2.57
S4	0.032	4.03
S5	0.040	3.96
S6	0.031	2.81
S7	0.030	2.66
S8	0.028	2.73
S9	0.032	4.04

PORK: Dependent variable LNPRICE

*Instrument list:* C, TREND, LNPINV, LNBPRICE, LNCPRICE, LNPCAPDI, SHIFT75, S1, S2, S3, S4, S5, S6, S7, S8, S9, S11

Independent variables	Coefficient	T-Statistic
C	4.487	21.52
TREND	0.005	9.50
LNPTIME	0.106	4.69
LNPINV	-0.153	-4.77
S3	-0.025	-2.61
S4	-0.025	-2.92

POULTRY: Dependent variable LNCPRICE

*Instrument list:* TREND, LNCINV, LNBPRICE, LNPPPRICE, INPCAPDI, SHIFT75, S1, S2, S3, S4, S5, S6, S7, S8, S9, S11

Independent variables	Coefficient	T-Statistic
C	3.536	12.40
TREND	0.004	5.63
LNCTIME	0.145	4.70
LNCINV	-0.219	-5.07
S1	0.043	3.43
S2	0.059	4.67
S7	0.068	5.05
S8	0.068	4.42
S9	0.073	5.43

TABLE 2

Interval estimates of  $1/\varepsilon$  and observed markups for meat and poultry

Product	95% interval estimate of $1/\varepsilon$	Range of observed markup 1960–1980
SHIFT75 included in instruments list		
Beef	[0.040, 0.156]	[0.042, 0.070]
Pork	[0.062, 0.151]	[0.063, 0.096]
Poultry	[0.084, 0.205]	[0.101, 0.169]
SHIFT75 excluded from instrument list		
Beef	[0.039, 0.148]	[0.042, 0.070]
Pork	[0.062, 0.151]	[0.063, 0.096]
Poultry	[0.081, 0.203]	[0.101, 0.169]

Of interest to our pricing model are the coefficients associated to inventory sales time series  $\text{LNBTIME}$ ,  $\text{LNPTIME}$  and  $\text{LNCTIME}$ . These are estimates of the inverse of elasticity  $\varepsilon$ . Table 2 provides the 95% interval estimates of  $1/\varepsilon$  for each commodity together with the range of markups observed for each product over the twenty year period 1960–1980. For each product, all markups applied over the sample period are contained in the interval estimates of  $1/\varepsilon$ . This is also the case when  $\text{SHIFT75}$  is excluded from the list of instruments. This is strong evidence in support of the hypothesis that meat and poultry wholesalers maximize average per unit time profit over the sales time of their inventory.

The compatibility of the model with the data, and the continuity in wholesale inventory and pricing policy that it suggests, is found in a context where the relative shares of the meat and poultry markets have undergone substantial changes. As reported by Trapp (1985), over the past 30 years the relative shares of beef and pork have been reversed, pork losing its dominance, while poultry has steadily increased its market share. Moreover inventory-to-sales ratios as well as markups are of significantly different magnitudes for beef, pork, and poultry, as shown in Table 3.

This underlying diversity speaks in favor of the robustness of the model.

TABLE 3

Average inventory-to-sales ratios and markups, 1960–1980

	Average inventory-to-sales (months)	Average markup (%)
Beef	0.196	6.9
Pork	0.247	8.0
Poultry	0.399	12.7

## CONCLUSION

This paper examines meat and poultry wholesale data to determine whether meat producers can be described as choosing price to maximize profit over the sales time of inventory. Price is expressed as a function of inventory sales time and inventory for three commodities – pork, beef and poultry. The system of inverse sales lag functions thus obtained is estimated using iterative three-stage least squares, and yields interval estimates for the inverse of the price elasticity of the sales time of inventory,  $1/\varepsilon$ , for each product. If wholesalers maximize average per-unit-time profit over the sales time of inventory,  $1/\varepsilon$  must match markup over the average cost of goods sold. Our interval estimates of  $1/\varepsilon$  contain all the markups applied by beef, pork, and poultry wholesalers between 1960 and 1980. The econometric evidence therefore supports the hypothesis that meat wholesalers maximize average per-unit-time profit over inventory sales time.

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## APPENDIX I

Formally, competition can be introduced by making firm  $i$ 's ( $i \in I = [1, 2, \dots, n]$ ) demand function depend on  $j \neq i$ 's strategies. Thus  $i$ 's sales lag function can be written  $t_i = t_i(p_i, Q_i, p_{j \neq i}, Q_{j \neq i})$ . A Nash equilibrium in this context is defined as a  $2n$ -tuple  $(p_{i \in I}^*, Q_{i \in I}^*)$  such that for all firms  $i$ ,  $(p_i^*, Q_i^*)$  maximizes  $i$ 's per-unit-time profit  $\pi_i$  given  $(p_{j \neq i}^*, Q_{j \neq i}^*)$ . Existence of such an equilibrium can be argued provided each firm's per-unit-time profit function has a unique maximum, and is continuous in all the variables, and that firms choose prices and quantities that are bounded above by a finite number. At the Nash equilibrium, each firm's optimal markup will still be expressed as the inverse of  $\varepsilon$ , where  $\varepsilon$  is a function of all prices and quantities. Thus, in an imperfectly competitive setting, estimating  $1/\varepsilon$  will still yield a statistic to be compared to true markup as long as the industry is assumed to be in Nash equilibrium or close to it.

## APPENDIX II

*Data sources and construction*

A copy of the data and of the regressions run is available from the author upon request.

### 1. Markup over the cost of materials and production workers

In census years for beef and pork, and for all years in the sample for the meat aggregate of beef, veal, mutton and pork and for poultry:

$$m = \frac{\text{Value of shipments} - \text{Cost of materials} - \text{Payroll production workers}}{\text{Value of shipments}}$$

Estimating beef and pork markups in non-census years was done with reference to markup for all meats. The method of computation is shown by example for beef markup between census years 1963 and 1967. Census data for meat and beef markups in % are as follows:

	Meat	Beef
1963	8.50	7.50
1964	9.34	
1965	8.24	
1966	7.41	
1967	8.35	6.92

Beef markup in 1963 is 88.24% of meat markup. In 1967 it has dropped to 82.87%. Assuming this decline takes place at a constant rate over the period, beef markup as a proportion of total meat markup dropped by 1.58% per year from 1963 to 1967. Thus, in 1966 beef markup is estimated to be at 84.18% of total meat markup or 6.24%. This is, of course, an ad hoc procedure. It assumes implicitly that changes in the relationship of beef or pork markups to total markups are smooth between census years. This does not seem implausible given that changes in this proportion from one census year to the other are, typically, small. Markups as recorded in the Census of Manufactures for census years, in the Annual Supplements to the census in interim years, and computed using the above method for beef and pork in non census years, are given in Table A.

### 2. Inventory and pricing data

#### *Single-source series: All commodities*

- PCAPDI is per-capita disposable income (monthly). Source: Survey of Current Business.
- Sales is production + change in stocks for the period. Source: Survey of Current Business.
- Inventory-to-sales: Calculated as beginning of period inventory divided by sales of previous period. Source: Survey of Current Business.

*Beef.* Survey of Current Business series aggregate beef and veal. To obtain series for beef, these were adjusted by multiplying by a monthly veal–beef ratio whose construction is illustrated by example using January 1975 data. January 1975: 3152 thousand cattle and 284 thousand calves are slaughtered. USDA Agricultural Statistics reports, yearly, the average live weight at slaughter of cattle and calves. For 1975, calves were 1009 lbs (458 kg) on average at slaughter, and calves were 227 lbs (103 kg) on average. Using this information, the January 1975 veal–beef ratio  $VBRAT$  is computed as follows:

$$\begin{aligned}
 VBRAT &= \frac{\#cattle \text{ slaughtered} \times 1009}{\#cattle \text{ slaughtered} \times 1009 + \#calves \text{ slaughtered} \times 227} \\
 &= \frac{3152 \times 1009}{3152 \times 1009 + 284 \times 227} = 0.9801
 \end{aligned}$$

TABLE A

Markup over the cost of materials and payroll of production workers

Years	Meat	Beef	Pork	Poultry
1958	7.96	7.12	8.43	9.18
1959	8.91	7.95 *	9.36 *	10.13
1960	9.21	8.19 *	9.60 *	10.09
1961	8.73	7.75 *	9.03 *	10.41
1962	8.92	7.89 *	9.16 *	10.15
1963	8.50	7.50	8.66	10.27
1964	9.34	8.11 *	9.18 *	10.27
1965	8.24	7.05 *	7.81 *	11.00
1966	7.41	6.24 *	6.77 *	11.88
1967	8.35	6.92	7.36	10.70
1968	8.72	6.83 *	7.84 *	12.18
1969	7.85	6.57 *	7.20 *	14.49
1970	8.77	7.38 *	8.20 *	13.58
1971	10.05	8.49 *	9.58 *	14.74
1972	7.54	6.40	7.33	13.09
1973	7.66	6.47 *	7.32 *	14.58
1974	8.33	7.00 *	7.82 *	13.81
1975	8.45	7.07 *	7.80 *	16.89
1976	8.67	7.22 *	7.86 *	15.27
1977	7.51	6.22	6.69	12.70
1978	6.51	5.07 *	6.33 *	15.47
1979	7.48	5.47 *	7.93 *	13.12
1980	7.48	5.15 *	8.65 *	12.22
1981	7.45	4.82 *	9.40 *	10.20
1982	8.49	5.16	11.68	11.35

Source: Census of Manufactures and Annual Supplements. \*, Estimated



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