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INTRODUCTION

This study is designed to provide information on the behavior of consumers and marketing agencies in the meat-livestock sector of the economy. The quarter will be used as the period of observation and emphasis will be placed on beef and pork. Equations will be designed and estimated statistically from post World War II data in an attempt to explain the behavior of the quantity demanded at retail, the wholesale to retail margin, the farm to wholesale margin and the change in cold storage stocks for these two commodities.

The study of this sector of the economy using quarterly data offers an opportunity to employ the use of distributed lags at several levels of the marketing system. The importance of time rates of change and the difference between the "short run" and the "long run" have been recognized in the economic theory of consumer demand as well as in the theory of the firm (e.g.73, pp. 45, 111). However, most empirical studies have attempted estimation based primarily upon static hypothesis. As the period under consideration becomes shorter the importance of dynamic considerations increases. Thus it is hypothesized that it is possible to observe some of the dynamic aspects of consumer, retailer and packer behavior when working with quarterly data.

The importance of beef and pork and the variation in production and prices characteristic of them make the study
of these commodities interesting and important. Approximately 20 per cent of the consumer's food dollar is spent on beef and pork, the two most important meat products (92, p. 46). Of this total about 60 per cent is received by farmers and 40 per cent is retained by marketing and processing agencies. The receipts at the farm level from beef and pork marketings represent some 28 per cent of the total cash receipts of farmers (87).

Considerable seasonal variation occurs in meat production and marketing. For example, almost 30 per cent of the yearly production of pork is marketed during the fourth quarter (Oct., Nov., Dec.) while approximately 20 per cent is marketed during the preceding quarter.¹ During the fourth quarter farm prices for hogs drop to 91 per cent of their yearly average while retail prices are typically only one per cent below their yearly average. Cold storage stocks of beef and pork move in response to the shifts in production during the year. Pork stocks reach their seasonal low near the first of November and their seasonal high near the first of March. Beef stocks generally peak during January and reach a low point in August. Although stocks reduce seasonal variation in consumption below the variation in production, considerable seasonal

¹The percentages quoted in this section were computed from data for the period 1949 to 1957 given in the Appendix.
variation in consumption remains. Consumption of pork in­creases about 30 per cent from the third quarter to the fourth quarter while production generally increases about 45 per cent.

The seasonal variation in production and consumption of beef is much smaller than that exhibited by pork. Production is lowest during the second quarter and highest during the fourth quarter, production during these quarters being some 97 and 102 per cent of the yearly average. Beef consumption is generally largest during the third quarter, balancing some­what the small consumption of pork at that time. Retail prices for both beef and pork are generally lowest during the first quarter and highest during the third quarter.

Marketing margins, i.e., the difference between prices at successive marketing levels, show considerable seasonal vari­ation. They are generally widest during the latter part of the year, the period of increasing farm supplies. Also, move­ments in margins are an important component of the total price variation. Breimyer (10) states that 43 per cent of the vari­ation in quarterly average farm prices of choice cattle from 1953 to mid 1956 was accounted for by varying marketing mar­gins and 57 per cent by fluctuations in the retail price of beef. For pork, where the total variation in prices is greater, changes in marketing margins still accounted for 20 per cent of the variation in prices of hogs at the farm level.
A USDA publication on pork marketing margins emphasized the importance of margins and the speed of market adjustment (91, p. 4):

It appears that $2.50 of the $9.00 decline in the price of live hogs at Chicago from June to December, 1955, was accounted for by failure of retail pork prices to fall as rapidly as farm prices of hogs.

Meat packers or processors need information on the seasonality of marketings in order to organize their operations to meet changing supplies. Further they need to link information on projected supplies with information on the seasonality of consumer demand to reach optimum storage programs. The gains from such increased knowledge by packers as a group could be shared by farmers in the form of higher average prices, by consumers in the form of a more desirable time distribution of consumption, and by packers in the form of higher net profits.

Livestock producers naturally are affected by the parameters of the demand function facing them. Numerous competent studies of the demand for beef and pork have been made using yearly data (e.g., 23, 61, 99). However, the performance of the market in such periods as late 1955 suggests that use of such studies for price predictions for periods less than a year may err considerably. Additional information on the performance of margins and consumer demand for periods of less than a year would improve the ability to predict the movement of farm prices.
The present levels of feed grain stocks and the continued presence of the hog cycle have increased interest in possible government programs directed toward the feed grain-livestock sector of the economy. Knowledge of seasonal variation and of market structure is necessary for the consideration and development of such programs.

Little work has been published which attempts statistical estimation of parameters to explain the movements in marketing margins. The USDA has published (84, 91) some work on margins, but the author is unaware of any published studies which have gone beyond a regression of price at one level on the price at another marketing level.

This brief discussion has indicated that information on the functioning of this sector of the economy should be of considerable use.
THEORETICAL CONSIDERATIONS

Consumer Demand

The Paretoan theory of consumer behavior assumes that the individual is guided in his consumption decisions by a well-defined preference or utility system. This preference system can be expressed as a utility function $U(q_1, q_2 \ldots q_n)$ of the quantities of the $n$ goods. Pareto first recognized that any positive monotonic transformation of $U$ will give the same results. Thus, it is not necessary to assume that utility is cardinally measurable. The property required of $U$ is that it define the marginal rates of substitution of one good for another,

$$\frac{\partial U}{\partial q_i} \neq \frac{\partial U}{\partial q_j}$$

Indifference curves or the graphic presentation of these substitution rates is often taken as the starting point in a discussion of consumer behavior. To derive the properties of demand functions it is generally assumed that the goods are homogeneous and divisible and that the utility function has continuous second derivatives, is non-decreasing and is convex in the sense that constrained maxima are unique.

A consumer faced with a given set of prices acts so as to maximize the function $U$ with the restriction that his total
expenditure must equal his income, \( \sum p_i q_i = Y \). Solving this problem with a Lagrangean multiplier yields the following system,

\[
\begin{align*}
\frac{\partial U}{\partial x_i} - \lambda p_i &= 0 \\
\sum p_i q_i &= Y
\end{align*}
\]

where \( \lambda \) is the Lagrange multiplier. From this it is seen that the marginal rate of substitution between any two goods must equal the ratio of their prices, i.e.,

\[
\frac{\frac{\partial U}{\partial q_i}}{\frac{\partial U}{\partial q_j}} = \frac{p_i}{p_j}
\]

Further the system may be solved for the demand functions wherein the quantity of each good is expressed as a function of all prices and income.

\[q_i = f_i(p_1, p_2, \ldots, p_n, Y)\]

The assumption that the utility function is independent of income and prices leads to the well known homogeneity property of demand equations. Specifically, the demand equations are homogeneous of degree zero in prices and income and hence multiplying all prices and income by a constant leaves the quantity demanded unchanged. This property makes it possible to choose one price as the numeraire (say the price of the \( k \)th commodity) and write the demand function of the \( i \)th good as

\[q_i = h \left( \frac{p_1}{p_k}, \frac{p_2}{p_k}, \ldots, \frac{p_n}{p_k}, \frac{Y}{p_k} \right)\]

The market demand schedule for a commodity can be
obtained by summing the individual demand curves.

The price elasticity of demand is defined as:

$$ \frac{\partial q_1}{\partial p_1} \cdot \frac{p_1}{q_1} = e_p $$

This concept is useful since being independent of the units of measurement, it represents the percentage change in quantity resulting from a one per cent change in price. The income elasticity is defined in a similar manner as:

$$ \frac{\partial q_1}{\partial Y} \cdot \frac{Y}{q_1} = e_Y $$

Certain dynamic aspects have been added to the static theory of consumer behavior. Stigler (73, p. 95) gives some of the reasons for expecting the elasticity of demand to increase with time. (As will be shown, this is another way of saying that the preceding prices and/or quantities are important determinants of the current quantity demanded.) The presence of technological rigidities, imperfections in the market, and habit are advanced to explain why the full effect of a price change may not be realized immediately.

Technological rigidities include such factors as the durability of a good and previous commitments for present purchases. In addition it may be necessary to purchase related goods to fully enjoy the benefits of the one whose price has changed. Imperfections in the market pertain primarily to imperfect knowledge of price changes. It should be pointed out that acquiring knowledge generally entails the
expenditure of effort, time and perhaps money by the consumer (e.g., "shopping around"). Thus there may be a considerable lapse of time before all consumers are aware of the new price. Habit or inertia is almost self-explanatory. It is easier to continue the previous pattern of expenditure rather than make the conscious effort of reorganization. The consumer may wait until he feels that the price change is permanent before changing his pattern of purchases.

The work of Duesenberry (16), Modigliani (53) and Friedman (28) suggests that past behavior and past incomes are important determinants of current consumption. Although these writers were concerned primarily with aggregate consumption and savings their work has important implications for the study of demand for individual commodities.

Friedman has hypothesised that "permanent" consumption is a constant proportion of "permanent" income. The important determinant of consumption is not the income which is observed (this is "permanent" income plus a transitory component), but the consumer's concept of his long run normal income. The consumer's concept of normal income is based upon his past experience and his expectations of the future. In the empirical portion of his monograph Friedman uses a weighted average of past incomes as an approximation of permanent income.

Friedman's work was preceded by that of Modigliani and Duesenberry. They hypothesised that the highest previous
income as well as the current income is an important determinant of current consumption. The highest previous income is introduced on the supposition that consumers attempt to maintain consumption in the face of a reduction in income. That is, once a consumer has become accustomed to a certain level of expenditure he prefers (at least for a time) to decrease his assets and/or rate of saving in an attempt to maintain this level. Modigliani argues further that the long time movement in income is upward and hence a period of decreasing income will be considered a temporary phenomenon by consumers.

Duesenberry's arguments on the nature of utility are of considerable interest. He has argued that it is incorrect to assign to the consumer a utility function with well defined parameters which expresses utility as a function of absolute quantities. Rather he pictures the consumer in a continual process of learning. His tastes, rather than being fixed, are influenced by his past experience and by the observed consumption patterns of others. By experimentation and observation he discovers and develops desires for new goods and discovers new uses and/or substitutes for those presently consumed. The desire to spend is induced by contact with the goods consumed by others. Such a description of consumer behavior can be formalized by expressing consumption as a function of the individual's past consumption and the past consumption of others. Thus, these ideas furnish a basis for
introducing past consumption into a demand function.

Possible forms of consumer demand equations which contain non-static elements can now be considered. First a static demand equation representing the level of consumption occurring if income and prices have been stable for a "long" time is written as

\begin{equation}
Q_{1} = aP_{1} + bP_{2} + cY
\end{equation}

where \( Q_{1} \) designates the quantity of commodity "1" demanded and \( P_{1} \) and \( P_{2} \) the retail price of commodities "1" and "2", respectively. This simplified demand equation is written as a linear approximation. The following discussion would be unaltered if the equation were treated as linear in logarithms.

Next the variables are dated and it is further assumed that the current quantity depends not only on current prices and income but upon previous prices and income.

\begin{equation}
Q_{1t} = \sum_{i=0}^{n} a_{i}P_{1t-i} + \sum_{i=0}^{n} b_{i}P_{2t-i} + \sum_{i=0}^{n} c_{i}Y_{t-i}
\end{equation}

Equation 2 states that quantity is determined by income and prices taken with a distributed lag. One might attempt to estimate equation 2 directly by estimating a multiple regression of \( Q_{1t} \) on current and lagged prices and income. This approach was taken by Alt (2). However, such a procedure has certain disadvantages. For example if it is desired to estimate equation 2 and lags of one period only are considered, i.e., \( n \) chosen equal to one, the regression contains six
explanatory variables. Consideration of two period lags would increase the number of explanatory variables in the regression to nine and so on. Each time the lag is increased one period three variables are added to the regression and the number of observations available for use in the regression is decreased by one. Further, as most economic series display some autocorrelation, the inclusion of multiperiod lags may introduce considerable correlation among explanatory variables. Thus direct estimation may result in large standard errors for the estimated coefficients. To overcome these difficulties it has been suggested that simplifying assumptions concerning the form of the lag be included in the model.

One of the more ingenious and useful assumptions is that put forth by Koyck (44). He suggests that the coefficients be approximated by a converging geometric series. Thus, for the coefficients of $P_{lt-1}$ above Koyck suggests that the $a_i$ be given by

$$a_{i-1} = \lambda a_i$$

(3)

It is not necessary to assume that 3 holds for all $i$ but the assumption may be modified to apply only for $i > k$. The method will be demonstrated for one dependent variable and for $k = 1$ giving:

$$Q_{lt} = a_0 P_{lt} + \sum_{i=1}^{\infty} \lambda^{i-1} P_{lt-1}$$

(4)

Lagging 4 one period and multiplying both sides of the equality by $\lambda$ yields:
(5) \[ \lambda Q_{lt-1} = \lambda a_0 P_{lt-1} + a_1 \sum_{i=2}^{\infty} \lambda^{i-1} P_{lt-1} \]

Rewriting 4 as

(4a) \[ Q_{lt} = a_0 P_{lt} + a_1 P_{lt-1} + a_1 \sum_{i=2}^{\infty} \lambda^{i-1} P_{lt-1} \]

and subtracting 5 from 4a gives

(6) \[ Q_{lt} - \lambda Q_{lt-1} = a_0 P_{lt} + (a_1 - \lambda a_o) P_{lt-1} \]

or:

(6a) \[ Q_{lt} = a_0 P_{lt} + (a_1 - \lambda a_o) P_{lt-1} + \lambda Q_{lt-1} \]

If one assumes that all the coefficients follow assumption 3 the reduced equation is:

(6b) \[ Q_{lt} = a_0 P_{lt} + \lambda Q_{lt-1} \]

This method can be expanded to more than one variate if it assumed that the distribution of lag is the same for each variate. This assumption is considerably stronger since it implies that the speed of reaction is the same whether the change in equilibrium quantity was induced by a change in income or by a change in price. Thus if it is assumed that

(7) \[ Q_{lt} = a_0 \sum_{i=0}^{\infty} \lambda^i P_{lt-1} + b_0 \sum_{i=0}^{\infty} \lambda^i P_{2t+1} + c_0 \sum_{i=0}^{\infty} \lambda^i Y_{t+1} \]

one obtains:

(8) \[ Q_{lt} = a_0 P_{lt} + b_0 P_{2t} + c_0 Y_{t} + \lambda Q_{lt-1} \]

The simplification in estimation flowing from Koyck's assumption becomes clear when 2 is compared with 8. The former contains a large number of explanatory variables while
the latter equation contains only the lagged value of the endogenous variable in addition to the current values of the explanatory variables.

Koyck (44, p. 22) points out that assuming a geometric series of coefficients is equivalent to assuming that the change in actual quantity is proportionate to the distance between quantity last period and the current equilibrium quantity. The equilibrium quantity is defined as that quantity which will be realized given enough time for complete adjustment to the existing prices and income. The equilibrium quantity, $Q^E_{t_1}$, can be obtained by setting $P_{t-1} = P_t$. From 7 one obtains for the equilibrium relation:

\[ (7a) \quad Q^E_{t_1} = \frac{a_0}{1 - \lambda} P_{t_1} + \frac{b_0}{1 - \lambda} P_{25} + \frac{c_0}{1 - \lambda} Y_t \]

Nerlove (56) has derived an equation similar to eight in a manner somewhat different from the approach of Koyck. Nerlove assumes the existence of an equilibrium equation such as equation 1 which gives equilibrium quantity as a function of prices and income. In addition an equation giving the rate of adjustment in quantity, i.e., the rate of movement toward equilibrium completes the system.

---

\[ \sum_{i=0}^{\infty} \lambda^i = \frac{1}{1 - \lambda} \quad -1 < \lambda < 1 \]
Thus the system is:

\[(1a) \quad Q_{1t}^E = a_0^'P_{1t} + b_0^'P_{2t} + c_0^'Y_t \]

\[(10) \quad Q_{1t} - Q_{1t-1} = (1 - \lambda) (Q_{1t}^E - Q_{1t-1}) \]

Substitution of \(1a\) into \(10\) gives a reduced equation of the same form as \(8\). Hence the assumptions underlying system \(1a\), \(10\) are equivalent to those of equation \(7\). That is, the adjustment equation, \(10\), implies the same geometric distribution of lag for all explanatory variables. Systems of the general type \(1a\), \(10\) will be investigated in the empirical section.

If the assumptions are accepted it is possible to obtain estimates of long and short run elasticities from the estimates of the coefficients of \(8\). The coefficients \(a_0\), \(b_0\), \(c_0\) represent the effect of current income and prices while \(\frac{a_0}{1 - \lambda}, \frac{b_0}{1 - \lambda}, \frac{c_0}{1 - \lambda}\) (equivalent to the \(a_0^', b_0^', c_0^'\) of \(1a\)) represent the long run effect of prices and income on quantity. If the equation is linear in logs \(\frac{s_0}{1 - \lambda}, \frac{b_0}{1 - \lambda},\)
\(\frac{c_0}{1 - \lambda}\) can be interpreted directly as long run elasticities.

In the equations just discussed lagged quantity entered the equation because of an assumption about the speed of reactions. The arguments of Duesenberry lead to the introduction of lagged quantity or lagged quantities to represent the current preferences. Ladd (46) has discussed the problem encountered in attempting to interpret the coefficients of equation \(8\) obtained empirically. The Koyck and Nerlove pro-
oedures assume the existence of an equilibrium quantity, mak­
ing possible elasticity estimates, while Duesenberry's ideas suggest that the equilibrium shifts as a result of current consumption change.

Retail Margin

It would be possible to describe the behavior of retail­
ers by specifying a retailer's demand curve and a retailer's supply curve. However, meat is a perishable commodity and is held for a short time by retailers. Thus, unless the period studied is very short the quantity demanded is identi­cal with the quantity supplied. It is therefore possible to replace the demand and supply equations by a reduced equation containing the margin between the demand (wholesale) price and the supply (retail) price.

Also retailer behavior is oriented toward the "mark up" from the wholesale price to the retail price. Retailers perform services but they price not their services, but commod­ities. Further the pricing policies vary for different com­modities. Perhaps the most common is the average cost pricing wherein a constant percentage markup is applied to the wholesale price (37, p. 2). Some commodities carry a con­stant dollar markup, while a combination of the constant and percentage markup characterizes others. The degree of compe­tition and the importance of the item in the family budget
influence the pricing behavior of retailers. The total marketing margin for meat has generally been characterized as a fixed dollar margin (70, p. 254).

Services performed by retailers differ somewhat for beef and pork. Beef is generally purchased from the packers as quarters or halves of carcasses. These are then cut into the retail cuts. Boning and trimming result in a weight loss of about 20 per cent (84, p. 13). In addition to cutting and trimming, portions of the meat may be ground and/or packaged. In the case of pork less cutting and trimming is performed at the retail level. Packers cure portions of the pork carcass and sell portions fresh. As a result they perform the majority of the cutting.

From a purely theoretical point of view the retailing operation might be viewed as a multiproduct firm purchasing raw materials, performing additional services on these materials and then selling the finished products. Carrying such an argument forward leads to an analysis based upon the raw material and factor prices. Further, the traditional firm theory would lead one to expect an upward sloping marginal cost curve in the short run.

It does appear that over a fairly long period margins are influenced by movements in marketing costs. For example there has been a gradual widening of margins since World War II associated with rising prices of inputs. Of the costs,
labor costs are the most important, accounting for approximately two-thirds of all costs in retailing (86, p. 14).

In the short run, however, it has been argued that all costs, including labor, can be considered fixed (37, p. 4). Thus the short run marginal cost curve is horizontal and the only variable important in retail pricing, other than the behavior of competitors and custom, is the wholesale price. Holdren (37, p. 4) argues further that in such a situation the optimum behavior for a retailer is to change retail prices by one-half the change in wholesale prices. This result can be obtained by equating marginal cost which equals wholesale price to the marginal revenue associated with a straight line demand curve of the form $K - bQ = P_R$

$$MC = P_W = K - 2bQ = 2P_R - K$$

$$\frac{dP_R}{dP_W} = 1/2$$

where $P_W$ refers to the wholesale price and $P_R$ to the retail price.

This hypothesis may be modified to explain movements in wholesale and retail prices which are in proportions other than two to one. If it is assumed that the optimum rate of change is

$$\frac{dP_R}{dP_W} = \beta$$

the resulting demand curve is
Thus a $\beta$ less than one-half will occur if the retailer believes his demand curve to be concave to the origin. This may well be realistic for such a curve can be considered a smooth modification of the "kinked" demand curve of oligopoly theory.

A tendency for changes in retail prices to lag behind changes in wholesale prices has been observed and the USDA bulletin on pork margins (91, p. 18) advances the following reasoning to explain the lag in retail price changes. It is reasoned that when wholesale price falls retailers at first have little incentive to lower retail prices; they merely widen margins. However, should the lower wholesale prices be maintained or the wholesale prices continue to fall competition among retailers will lead to reductions in retail prices and in retail margins. Conversely on a price rise retailers hesitate to change retail prices until the increase in the wholesale price becomes substantial or has existed for some time.

The above considerations lead to the following possible explanation of the behavior of the wholesale to retail margin:

\begin{align}
(5) \quad M_{Rt}^B &= aC_{Rt} + bP_{Wt}^B \\
(6) \quad M_{Rt}^B - M_{Rt-1}^B &= \alpha_0 (M_{Rt}^{BE} - M_{Rt-1}^{BE}) + \alpha_1 \Delta P_{Wt}^B + \alpha_2 \Delta P_{Wt}^P
\end{align}

This system introduces the type of notation to be used
throughout the remainder of the thesis. The superscripts denote the commodity and subscripts the marketing level and the time period. In addition the superscript $E$ is used to indicate the equilibrium quantity and the greek $\Delta$ to indicate the one period change in the variable. Thus $M_{Rt}^{BE}$ denotes the equilibrium wholesale to retail (retailer's) margin for beef at time $t$, $M_{Rt}^B$ the retail margin existing at time $t$, $P_{Wt}^P$ the wholesale price of pork at time $t$, $P_{Wt}^B$ the wholesale price of beef at time $t$, $\Delta P_{Wt}^B = P_{Wt}^B - P_{Wt-1}^B$ the change in the wholesale price of beef from the period $t-1$ to the period $t$ and $C_{Rt}$ cost factors affecting the retailing operation.

The equilibrium margin for beef is given as a linear function of the costs of retailing and of the wholesale price of beef. The wholesale price is introduced to explain any tendency toward a percentage markup. The rate of change in the retail margin is expressed as a function of the difference between last quarter's margin and the current equilibrium margin and of the rate of change in the wholesale prices of beef and pork. The change in the wholesale price of pork is included on the assumption that the substitutability in consumption of beef and pork leads to interdependency in retail price movements.

Substituting the equilibrium margin from 5 into 6 it follows that:
This model assumes that retailers act primarily as quantity adjusters and that price changes are initiated in the wholesale market. That is, if demand increases it is assumed that retailers increase their orders but do not seriously increase retail prices and widen their margins. If this assumption is false, consumer income or a similar measure of retail demand should be added to the system. For example, the change in income might be included in the adjustment equation or income might be included in the equilibrium equation on the assumption that consumers demand additional services as income increases.

Packer - Wholesale Behavior

This section of the marketing channel is dominated by meat packers, although there are a considerable number of independent wholesalers. Direct sales from meat packers to retailers are the most common transaction while the sales of packing house branches and independent wholesalers are of secondary importance (98, p. 323; 324). About three-fourths of meat wholesaling is performed by meat packers either directly or through branches.

The behavior of this section might be represented by a
demand curve for livestock and a supply curve for meat. The
difference between the quantity supplied and the quantity
demanded represents the accumulation of stocks by packers.
Rather than attempt to describe behavior of this marketing
sector with supply and demand equations, two equations which
can be derived from the supply and demand equations will be
used; a margin equation, and a storage equation. The margin
represents the difference between the demand price and the
supply price, while the change in stocks represents the dif­
ference between the quantity supplied and the quantity demand­
ed.

Storage stocks

Inventories are typically accumulated during the period
November to March and liquidated during the remainder of the
year when declining farm supplies result in price rises. Pork
stocks are the most important and show the greatest seasonal
variations. During the period 1949-58 cold storage stocks of
pork ranged from a high of 822 million pounds in the spring
of 1952 to a low of 134 million pounds in the fall of 1957.
The average accumulation of stocks was almost 300 million
pounds, stocks averaging about 218 million pounds at the end
of the third quarter and 516 million pounds at the end of the
first quarter.

Beef stocks reach their low point earlier as well as
reaching a seasonal peak sooner than pork stocks. Stocks were as low as 60 million pounds and as high as 202 million pounds during the 1949-58 period. The seasonal change in stocks averaged close to 100 million pounds.

Meat inventories are desired for two purposes: to meet the day to day operational requirements and in anticipation of a price rise. Klein (40, p. 13) demonstrates the importance of price anticipations in the following manner. The anticipated profits of the firm for the period T are given by

$$\pi^* = \int_0^T \left[ p*(Q_1 \frac{ds}{dt}) - \sum x_1 q_1 + \frac{d(ps)^*}{dt} - f(s) \right] e^{-rT} dt$$

where the asterick, *, is used to denote anticipated values; \( \pi \) represents profit; \( p \) the price of output; \( Q \) the quantity of output; \( \frac{ds}{dt} \) the time rate of change in stocks; \( x_1 \) the price of inputs; \( q_1 \) the quantity of inputs; \( \frac{d(ps)^*}{dt} \) the anticipated time rate of change in the value of stocks; and \( f(s) \) storage costs as a function of the quantity of stocks.

To maximize \( \pi^* \) the partials of \( \pi^* \) with respect to the \( q_1 \) and \( s \) are equated to zero. The partials with respect to the \( q_1 \) give 1 equations which represent the demand for factors. The equation obtained from the partial with respect to \( s \),

$$\frac{\partial \pi^*}{\partial s} = 0$$

gives
This last equation shows that the maximization of anticipated profit requires that the marginal cost of storage equal the anticipated change in price.

However the expected price change is not an observable variable and hence cannot be directly included in a regression equation. A similar problem arises in the analysis of supply. Entrepreneurs commence production on the basis of price expectations held at the beginning of the production period, but these expectations are impossible to observe.

Nerlove (59), in his work on supply elasticities, has suggested a model for generating price expectations which is based upon the Hicksian concept of the elasticity of expectations. Hicks (35, p. 205) has defined the elasticity of expectations as "the ratio of the proportional rise in expected future prices of x to the proportional rise in current prices."

This definition might be interpreted as

\[
\frac{dp^*_t}{dp^*_t} \frac{p_t}{p^*_t} = \alpha
\]

where differentials are used to represent time rates of change. If the definition is expressed in finite differences in logs it might be written as

\[
p^*_t - p^*_{t-1} = \alpha (p_t - p_{t-1})
\]

But Nerlove argues that the Hicksian definition, "implies
that prices have actually been 'normal' until some change occurred" (56, p. 22) and hence that the change in expected price should be proportional to the deviation in current price from the previously expected price. This gives

\[ p^*_t - p^*_{t-1} = \alpha (p_t - p^*_{t-1}) \]

This model has been used by Nerlove in estimation of elasticities of supply for several agricultural commodities. It is probable that the model is more applicable to a situation where production is fixed for a discrete time period once a decision has been made than to the more flexible and dynamic inventory case, which is characterized by a considerable period of accumulation as well as depletion. In the latter case expectations may be formulated for several future periods and these expectations reviewed, if not continuously, at least periodically.

Unfortunately little past work is available to use in isolating the criteria used by meat packers in making storage decisions and formulating price expectations. Tolley and Harrell (82, p. 45) interviewed executives of packing firms on the formulation and execution of storage decisions. These interviews did not give a clear picture of relevant variables considered by the decision makers. They did indicate that increasing physical storage costs were seldom a factor since public warehouse facilities as well as packer owned facilities were utilized in the storage operations. Tolley and Harrell
conclude:

The average level of seasonal inventories is primarily explained by risk, and variations in seasonal inventories relate to price expectations which are volatile and often inaccurate.

However, they go on to say that packers are fairly successful in predicting changes in supply but unsuccessful in forecasting shifts in demand. The USDA publishes periodic information which can be used to predict livestock marketings. Probably the most important of these publications is the "Pig Crop Report" which gives the number of sows farrowing and the farrowing intentions. Since the feeding period is varied only moderately, marketings are closely related to the farrowings 6 to 8 months previous. Packers indicated to Tolley and Harrell (82) that the fall pig crop reports were used when making decisions concerning the accumulation of storage stocks.

Some additional observations on the change in stocks seem possible. The level of stocks will be associated with the change in farm production for two reasons. First, an increase in production will lead to more operating or pipeline stocks. If there is a lag before wholesale prices fall it means that packers are accumulating stocks. Tolley and Harrell believe that this pipeline swelling results in only moderate increases in storage stocks, however. Secondly, an increase in production leads to a fall in the current price which increases the difference between the expected future
price and present price.

It is also to be expected that beginning stocks will influence the level of ending stocks. It is logical to ex­pect a lag between the decision to liquidate or acquire stocks and the completion of the change in inventory and certainly during periods of liquidation the beginning stocks place a limit on the depletion. Also the stocks of beef and pork should be related, or the stocks of one a function of the ex­pected change in production of the other.

With this background it is possible to construct several models as possible explanations of the behavior of storage. It is difficult however to introduce expectations into a model without greatly increasing the number of variables in the equation to be estimated. For example, consider the fol­lowing expectational model where expectations are generated in the manner suggested by Nerlove (57, p. 23). The variables are defined as follows: \( s_t^{BE} \) denotes the equilibrium level of beef stocks at the end of period \( t \); \( \Delta P_{Wt+1}^{B*} = P_{t+1}^{B*} - P_t^B \) de­notes the expected change in the wholesale price of beef from period \( t \) to period \( t+1 \) where the expectation is formulated at time \( t \); \( \Delta Q_{Ft+1}^{B*} = Q_{Ft+1}^{B*} - Q_t^B \) denotes the analogous expected change in farm marketings in beef.

\[
(1) \quad s_t^{BE} = a \Delta P_{Wt+1}^{B*}
\]

\[
(2) \quad \Delta P_{Wt+1}^{B*} = b_0 / a \Delta Q_{Ft+1}^{B*} = b_1 / a \Delta Q_{Ft+1}^{B*}
\]
\( \frac{B^B_{t+1}}{F_t} - \frac{B^B_t}{F_t} = \alpha_0 (\frac{B^B_t}{F_t} - \frac{B^B_{t-1}}{F_t}) \)

or equivalently:

\( \Delta \frac{B^B_t}{F_{t+1}} = (1 - \alpha_o) (\Delta \frac{B^B_t}{F_t} - \Delta \frac{B^B_{t-1}}{F_t}) \)

(4) \( \frac{P^P_{t+1}}{F_t} - \frac{P^P_t}{F_t} = \alpha_1 (\frac{P^P_t}{F_t} - \frac{P^P_{t-1}}{F_t}) \)

(5) \( s^B_t - s^B_{t-1} = \beta (s^B_{t-1} - s^B_{t-2}) \)

The expected price change has been expressed as a function of expected quantity changes since packers are apparently better able to predict changes in production and secondly such an approach allows explicit consideration of expectations concerning the substitute meat.

Equation 5 is included in the system on the assumption that technological factors prevent complete adjustment of stocks to the planned level within one period. The above system leads to the following reduced equation where the coefficients, \( C_i \), are combinations of the parameters in the system:

\( s^B_t = C_0 \Delta \frac{B^B_t}{F_t} + C_1 \Delta \frac{P^P_t}{F_t} + C_2 \Delta \frac{B^B_{t-1}}{F_t} + C_3 \Delta \frac{P^P_{t-1}}{F_t} \\
+ C_4 s^B_{t-1} + C_5 s^B_{t-2} + C_6 s^B_{t-3} \)

Thus it seems desirable to simplify the model in order to decrease the number of variables in the reduced equation, for it is highly doubtful if statistical estimation would yield reliable coefficients for five lagged variables.
One possible simplification is to retain the above model and add the further assumption that \( \alpha_0 = \alpha_1 = \alpha \). The estimation of both the pork and beef storage equations provides a check on this assumption. Each of the two equations will yield an estimate of \( \alpha \) and hence a comparison of the estimates makes it possible to evaluate the original assumption. The assumption that \( \alpha_0 = \alpha_1 = \alpha \) simplifies the reduced equation to

\[
(7) \quad s_t^B = (2 - \alpha - \beta)s_{t-1}^B - (1 - \alpha)(1 - \beta)s_{t-2}^B - \beta b_0(1 - \alpha)\Delta Q_t^B - \beta b_1(1 - \alpha)\Delta Q_t^P
\]

The expectational equations of the above system employ only two variables, past expectations and present marketings, to explain present price expectations. No doubt additional information is used to formulate expectations about future marketings. For example there appears to be good grounds for adding the change in farrowings to the expectational equation for pork quantity. Thus 4 becomes:

\[
(4a) \quad Q_{t+1}^P - Q_t^P = \alpha (Q_{t+1}^P - Q_t^P) + \gamma \Delta F
\]

and the reduced equation for pork stocks becomes:

\[
(8) \quad s_t^P = (2 - \alpha - \beta)s_{t-1}^P - (1 - \alpha)(1 - \beta)s_{t-2}^P - \beta b_0(1 - \alpha)\Delta Q_t^B - \beta b_1(1 - \alpha)\Delta Q_t^P + \gamma b_1 \Delta F
\]

The adoption of a different model for the generation of
expectations might be introduced to yield a reduced equation differing somewhat from 7. For example if it is assumed that

(9) \[ \Delta Q^*_t = g_0 \Delta Q_t \]

and the assumption of a lag in the adjustment of inventories is retained, an equation of the form

(10) \[ s^P_t = g_1 \Delta Q^B_t + g_2 \Delta Q^P_t + (1 - \beta) s^P_{t-1} \]

is obtained.

It may be remarked in passing that an expectation equation of the form 9 or a slightly expanded form such as

\[ \Delta Q^*_t = g_0 \Delta Q_t + g_1 \Delta Q_{t-1} \]

may be quite realistic for commodities such as pork which are characterized by marked seasonality and recurring cycles of production.

\textbf{Farm to wholesale margin}

The farm to wholesale margin represents the increase in value due to both the processing and wholesaling activities. Over the long run it appears that wholesale margins like retail margins are influenced by cost factors. Of these labor is the most important, representing approximately 50 per cent of the difference between the cost of livestock and the receipts from sales (84, p. 13).

Meat packing is a type of manufacturing characterized by dis-assembly rather than assembly. Thus application of tradi-
tional firm theory to the wholesale margin behavior leads one to expect an upward sloping marginal cost curve in the short run. In fact it appears that the cost of changing the level of operation is an important consideration in meat packing. An increase in livestock marketings means that additional employees must be hired and/or overtime paid to present employees to process the increased quantity. In such a situation margins tend to widen. Breimyer (10, p. 692) notes that margins widen more than the increase in costs due to "the desire of the entire meat trade for stability in both prices and volume of business." Conversely during periods of decreasing farm marketings packers compete to maintain the operation of their plant and to maintain the supply of products to their customers. As a result margins tend to narrow.

One would expect the wholesale margin for beef to be related to that of pork or to be related to the production of pork. Beef and pork are often processed in the same plants or by the same firms in different plants. The transfer of factors from beef processing to pork processing is probably limited by technological and institutional factors (e.g., labor unions and specialized assembly line type of processing.) Despite these limitations some substitutability is expected to exist. These considerations lead to the following possible explanation of wholesale margin behavior:
(1) \[ M^P_{Wt} = a_0 Q^P_{ft} + a_1 C_t \]

(2) \[ M^P_{Wt} - M^P_{Wt-1} = K_0 (M^P_{Wt} - M^P_{Wt-1}) + K_1 \Delta Q^P_{ft} + K_2 \Delta Q^P_{ft} \]

where \( M^P_{Wt} \) denotes the current equilibrium wholesale margin, \( Q^P_{ft} \) denotes the current quantity of farm marketings of pork and \( \Delta Q^P_{ft} \) denotes the difference between marketings at time \( t \) and at \( t-1 \).

The equilibrium margin is expressed as a function of costs and of the quantity processed. If the long run average cost is almost horizontal the coefficient for absolute quantity will be close to zero. The rate of change in margins is expressed as a function of the difference between the current equilibrium margin and the margin last quarter, and the rate of change in the production of beef and pork. Reduction of the above system yields:

(3) \[ M^P_{Wt} = K_0 a_0 Q^P_{ft} + K_0 a_1 C_t + (1 - K_0) M^P_{Wt-1} + K_1 \Delta Q^P_{ft} \]

\[ + K_2 \Delta Q^P_{ft} \]

The preceding discussion has considered lags introduced into the equation by rigidities. These include such factors as the time required to increase the level of the plants operation, the lag between receipt of livestock and sale in the wholesale market of the wholesale cuts, as well as the time required for firm managers to react to changed conditions. Similar variables could be introduced into the margin equation.
with an expectational model.

In the following model it is assumed that the equilibrium margin is a function of the expected change in farm marketing as well as the actual change. Further the assumption of lags due to rigidities is retained.

\[
(4) \quad M_{Wt}^{PE} = a_0 \Delta Q_{Ft}^{P*} + a_1 \Delta Q_{Ft}^{P}
\]

\[
(5) \quad Q_{Ft}^{P} - Q_{Ft-1}^{P} = \rho (Q_{Ft-1}^{P} - Q_{Ft-1}^{P*})
\]

\[
(6) \quad M_{Wt}^{P} - M_{Wt-1}^{P} = \alpha (M_{Wt}^{PE} - M_{Wt-1}^{P})
\]

The variables are as previously defined where the * denotes expected values. Thus \(Q_{Ft}^{P*}\) represents the marketings expected to occur during time \(t\). It is assumed that these expectations were formulated at time \(t-1\). Therefore \(\Delta Q_{Ft}^{P*} = (Q_{Ft}^{P} - Q_{Ft-1}^{P})\) is the expected increase in marketings formulated at time \(t-1\). The expected quantity is a weighted average of the quantity marketed last quarter and the quantity expected last quarter. This may also be written as:

\[
(5a) \quad \Delta Q_{Ft}^{P*} = (1 - \beta) (\Delta Q_{Ft-1}^{P*} - \Delta Q_{Ft-1}^{P})
\]

The system can be reduced to:

\[
(7) \quad M_{Wt}^{P} = (2 - \alpha - \beta) M_{Wt-1}^{P} - (1 - \alpha) (1 - \beta) M_{Wt-2}^{P}
\]

\[-(1 - \beta) \alpha (a_1 + a_0) \Delta Q_{Ft-1}^{P} + a_1 \alpha \Delta Q_{Ft}^{P}\]

If it is assumed that the equilibrium margin is proportional to the difference between the expected and realized farm quantity \((a_o = -a_1)\) \(\Delta Q_{Ft-1}^{P}\) disappears from the equation.
Under this assumption equation 7 is very similar to an equation such as 3 differing only by the margin lagged two periods $M_{Wt-2}$.
STATISTICAL CONSIDERATIONS

Least Squares and Simultaneous Techniques

The method of least squares has been widely used to estimate economic relationships from time series data. This method selects the linear combination of "independent" variables which best predicts the "dependent" variable. As the name implies, the procedure minimizes the sum of squared deviations of the actual observations from the predicted. The model is generally given in the form

\( Y = X\beta + \varepsilon \)

where \( Y \) is the vector of \( t \) observations on the dependent variable and \( \beta \) is a vector of coefficients for the matrix of independent variables, \( x_i \), and \( \varepsilon \) is the error vector. If it is assumed that:

(a) \( \varepsilon_1 \) is distributed normally with zero mean
(b) \( \text{E}(\varepsilon_i \varepsilon_j) = 0 \quad i \neq j \)
(c) \( \text{E}(\varepsilon_i^2) = \sigma^2 \)
(d) The \( x_i \) are fixed or \( \text{E}(x_i \varepsilon_i) = 0 \) all \( j \)

The estimates of \( \beta \), \( \hat{\beta} \) have the following desirable properties. They are linear functions of normal variates, hence they are distributed normally and it is possible to construct confidence intervals. They are unbiased estimates of \( \beta \), i.e., \( \text{E}\hat{\beta} = \beta \), and have the maximum likelihood properties of sufficiency and consistency. Further they are "best" esti-
mates, i.e., their variances are the smallest among all linear unbiased estimates.

If the assumption of normality is relaxed and it is assumed only that the \( e_i \) are distributed as some density function \( f(e) \) the estimates remain the best linear unbiased estimates. If the assumption of independent errors, (b), is relaxed the estimates remain unbiased but lose their efficiency properties.

The use of the least squares techniques in estimation of economic relationships has not been without criticism and discussion. Working (103) first discussed the problem of identification. He pointed out that each observation in a time series of prices and quantities represents the intersection of a supply and a demand curve. The ability to estimate a demand curve depends upon the stability of the supply curve. If the two showed simultaneous variation the least squares line would represent neither the supply curve nor the demand curve.

Haavelmo's (32) contribution in 1943 and the subsequent work of Cowles commission led to the method of estimation known as the simultaneous equations approach. Using this approach it is necessary to specify those variables which are believed to be mutually determined, the endogenous variables. Variables which are determined outside the system are called exogenous variables. In addition past values of the
endogenous variables may enter the equations. These latter
two types of variables can be grouped into a single class of
predetermined variables. The following is an example of a
simultaneous system.

(5a) \( (D) \quad q_t + a_0 p_t + a_1 y_t = e_{1t} \)
(5b) \( (S) \quad q_t + b_0 p_t + b_1 p_{t-1} = e_{2t} \)

The first equation represents the demand equation speci-
ifying that the quantity demanded is related to price, income
and a residual error term. The supply equation relates the
quantity supplied to current and lagged price. In this
example we assume that income is exogenous or determined out-
side the system. In the supply equation \( p_{t-1} \) is a predeter-
mined variable, "predetermined" in the sense that it is not
influenced by the endogenous variables.

The following assumptions are made:

(a) The predetermined variables are independent of the
\( e_{1t} \)
(b) The \( e_{1t} \) are distributed normally with \( \sigma_1^2 < \infty \) and
(c) \( E(e_{1t} e_{2t}) = \sigma_{12} < \infty \)
(d) \( E(e_{1t} e_{1j}) = 0 \quad i \neq j \)
(e) The \( e_{1t} \) result from incomplete specification of the
equation.
(f) The coefficients \( a \) and \( b \) are linear.

Thus the error is assumed to be associated with the equation
and to be independent of the predetermined variables in that
equation.

It has been shown (33) that if the system $5$ exists in fact the least squares estimating procedure will give biased estimates of the coefficients. The following method of estimation is then suggested. Solve the system for the endogenous variables $p_t$ and $q_t$ in terms of the predetermined variables. Fit the resulting equations by least squares and then transform the coefficients thus obtained into the coefficients of $5$.

In the simple system above both equations are just identified, i.e., the number of exogenous variables in the system and not in the equation is one less than the number of endogenous variables in the equation under consideration. In this pleasant case there exists a one to one correspondence between the coefficients of the reduced form and the coefficients of the original system. If the number of excluded exogenous variables equals or exceeds the number of endogenous variables in the equation, the equation is said to be over identified. This is the most common case and the method of limited information was developed to estimate the coefficients in such a case. The limited information estimates are consistent and as efficient as any method using the same amount of information. However considerable computational work is required to obtain the estimates.

The characteristics of least squares and limited informa-
tation estimates can be summarized in the following manner.

The least squares estimates are:

(a) relatively easy to compute
(b) have small variances
(c) can be expected to be biased if the equation estimated is part of a simultaneous system.

While limited information estimates are:

(a) More complicated and expensive computationally
(b) The variances of the estimates are greater than the variances of least squares estimates
(c) Are biased in small samples
(d) But the bias approaches zero as the sample size increases, i.e., they are consistent estimates.

Christ (13, p. 397) after considering the above points concludes:

Thus the question of which method to use for any finite sample size is still open, for we do not know how to tell whether the bias of the limited-information method at a given sample size is smaller than the least-squares method by enough to compensate for its bigger variance.

The recent work of Theil (76) and Basmann (6) has suggested an alternative method of estimating equations which are a part of a simultaneous system. The estimation proceeds as follows: choose one of the endogenous variables in the equation to be estimated, compute regressions of each of the remaining endogenous variables of the equation on the predetermined variables of the system and using the regression
equations compute the estimated values of the endogenous variables, and then compute the regression of the chosen endogenous variable upon the estimated endogenous and predetermined variables in the equation. The procedure is somewhat arbitrary since it depends upon the choice of the endogenous variable to serve as the dependent variable. However, it has been shown by the above authors that the estimates so obtained are consistent.

The "proximity theorem" of Wold (99, pp. 37, 189) gives some indication of the size of the bias associated with the least squares estimates of equations belonging to a simultaneous system. Suppose that a variable $x$ is treated as exogenous when in fact it is mutually determined (i.e., it is not independent of the residual). The bias is a function of the relative magnitude of the error variance and the correlation between the error and $x$. For the one variable case Wold illustrates this in the following manner. Given $y = \beta x + z^*$ the true relationship and $y = bx + z$ the observed, then:

$$E(b) = \frac{E(xy)}{E(x^2)} = \beta + \frac{E(xz^*)}{Ex^2} = \beta + r(xz^*) \frac{\sigma(z^*)}{\sigma(x)}$$

where $r(xz^*)$ is the correlation between $x$ and $z^*$. Thus if $r(xz^*)$ is small and $\frac{\sigma(z^*)}{\sigma(x)}$ is small, then the product (the bias) is small of the second order. The bias approaches zero as the variance of the residuals approaches zero just as the regression of $y$ on $x$ approaches the regression of $x$ on $y$ as
the correlation between \( x \) and \( y \) approaches 1.

Least squares estimating procedures will be used in this study. The relatively inexpensive nature of the computations makes possible the investigation of a greater number of alternative hypotheses.

Little a priori information is available to aid in selecting a specific form for several equations (notably the margin and storage equations) to be estimated, or in predicting the distributional properties of the residuals (the degree of serial correlation). Thus since the research funds available were not unlimited it was felt that the greatest amount of information could be obtained by the use of least squares. An obvious extension of this study would be the estimation of the equations by simultaneous methods.

Estimation of Equations Containing Lagged Endogenous Variables

The inclusion of lagged variables in the equation to be estimated complicates the estimation procedure and/or makes critical the assumptions about the residuals.

Hurwicz (38) has shown the existence of bias in the least squares estimates of \( \alpha \) in an equation of the form

\[
y_t = \alpha y_{t-1} + u_t
\]

if the estimates are obtained from small samples. However, the estimate of \( \alpha \) is consistent if the \( u_t \) are serially inde-
independent (51). The exact nature of the small sample bias is known only for samples of 3 and 4 and in certain limiting cases, but it appears that the bias becomes rather small in moderate sized samples (20 to 40) where $\alpha$ is not close to zero.

In his discussion of the estimation of distributed lags Koyck (44, p. 32) has demonstrated that the least squares estimate of the coefficient for the lagged endogenous variable is a consistent estimate only if the residuals of the reduced equation are serially independent. Koyck assumes the following equation

$$y_t = \alpha \sum_{i=0}^{\infty} \lambda^i x_{t-1} + u_t$$

which may be reduced to

$$y_t = a x_t + \lambda y_{t-1} + u_t - \lambda u_{t-1}$$

Then the probability limit of the least squares estimate of $\lambda$, denoted by $\hat{\lambda}$ is given by

$$\text{plim} \hat{\lambda} = \begin{vmatrix}
Ex^2_t & Ety_t x_t \\
Ex^2_t y_{t-1} & Ety_t y_{t-1} \\
Ex^2_t y_{t-1} & Ey^2_{t-1}
\end{vmatrix}$$

From 2 it follows that

$$Ey_t x_t = aEx^2_t + \lambda Ex_t y_{t-1} + Ex_t u_t - \lambda Ex_t u_{t-1}$$

$$Ey_t y_{t-1} = aEx_t y_{t-1} + \lambda Ey^2_{t-1} + Ey_{t-1} u_t - \lambda Ey_{t-1} u_{t-1}$$
where by hypothesis $EX_{t-1}u_t = 0$ for all $1$ and from $1$ it follows that:

$$
(6) \quad Ey_{t-1}u_t = a \sum_{i=1}^{\infty} \lambda^{i-1} EX_{t-1}u_t + Eu_{t}^{2} = Eu_{t}^{2}
$$

$$
(7) \quad Ey_{t-1}u_{t-1} = a \sum_{i=1}^{\infty} \lambda^{i-1} EX_{t-1}u_{t-1} + Eu_{t-1}^{2} = Eu_{t-1}^{2}
$$

Substituting 6 and 7 into 5 Koyck obtains

$$
(8) \quad \lambda = \begin{bmatrix}
EX_t^2 & Ey_t x_t \\
EX_t y_{t-1} & Ey_t y_{t-1} - Eu_{t}^{2} - Eu_{t-1}^{2} - \lambda Eu_{t-1}^{2} \\
EX_t^2 & Ey_t x_t \\
EX_t y_{t-1} & Ey_t^{2}
\end{bmatrix}
$$

which equals $\text{plim} \hat{\lambda}$ only if

$$
(9) \quad Eu_{t}^{2} = \lambda Eu_{t-1}^{2}
$$

Proposition 9 is satisfied if the residuals of the reduced equation are serially independent. Thus in all other cases the least squares estimate of $\lambda$ is an inconsistent estimate.

Nerlove and Addison (60, p. 879) have attached considerable significance to the fact that the addition of the lagged endogenous variable to statistical supply and demand equations greatly reduced the evidence of positive serial correlation in the residuals. They used a model of the form:

$$
(10) \quad x_t^E = bp_t
$$

$$
(11) \quad x_t - x_{t-1} = \delta (x_t^E - x_{t-1})
$$
to obtain the following equation:

\[ x_t = b\gamma p_t + (1 - \gamma)x_{t-1} + u_t \]

where \( u_t \) is the residual term. Equation 12 was fitted statistically and the results were then compared with those obtained from the regression equation:

\[ x_t = b'p_t + u'_t \]

Although the residuals from many of the regressions of type 13 displayed significant positive serial correlation the Durbin-Watson test yielded no significant values and only a few in the inconclusive range when applied to the residuals obtained from regressions of type 12.

It seems, however, that the counter argument is equally powerful. Namely, if the residuals in a "true" representation such as 13 are serially correlated, then the estimation of model 12 may lead to significant coefficients for the lagged endogenous variable and little evidence of serial correlation in the residuals. This argument is supported in the following discussion which considers the general problem.

To investigate the nature of the bias introduced when the model 12 holds and the residuals are serially correlated consider the general model:

\[ y_t = ax_t + by_{t-1} + u_t \]

\[ u_t = \rho u_{t-1} + e_t \]

\[ = \rho (y_{t-1} - ax_{t-1} - by_{t-2}) + e_t \]
If the regression
\[(19) \quad y_t = a'x_t + b'y_{t-1} + \epsilon_t \]
is estimated by least squares, the normal equations are:
\[(20) \quad a'\Sigma x_t^2 + b'\Sigma x_t y_{t-1} = \Sigma y_t x_t \]
\[(21) \quad a'\Sigma x_t y_{t-1} + b'\Sigma y_{t-1}^2 = \Sigma y_t y_{t-1} \]
and the probability limit of \( b' \) is given by
\[(22) \quad \text{plim } b' = \frac{\begin{vmatrix} \text{Ex}_t^2 & \text{Ex}_t y_t \\ \text{Ex}_t y_{t-1} & \text{Ey}_t y_{t-1} \end{vmatrix}}{\begin{vmatrix} \text{Ex}_t^2 & \text{Ex}_t y_{t-1} \\ \text{Ex}_t y_{t-1} & \text{Ey}_{t-1}^2 \end{vmatrix}} = \frac{\Delta b}{\Delta} \]
From 14
\[(23) \quad \text{Ex}_t y_t = a\text{Ex}_t^2 + b\text{Ex}_t y_{t-1} + \epsilon_t x_t \]
\[(24) \quad \text{Ey}_t y_{t-1} = a\text{Ex}_t y_{t-1} + b\text{Ey}_{t-1}^2 + \epsilon_t y_{t-1} \]
From 15
\[(25) \quad \epsilon_t y_{t-1} = \beta\text{Ey}_{t-1}^2 - \beta a\text{Ex}_{t-1} y_{t-1} - b\beta\text{Ey}_{t-2} y_{t-1} + \epsilon_t y_{t-1} \]
Noting that \( \text{Ex}_{t-1} y_{t-1} = \epsilon_t y_t \) etc., 25 is substituted in 24 to obtain
\[(26) \quad \text{Ey}_t y_{t-1} = a\text{Ex}_t y_{t-1} + b\text{Ey}_{t-1}^2 + \beta\text{Ey}_{t-1}^2 - \beta a\text{Ex}_t y_t - b\beta\text{Ey}_t y_{t-1} \]
or

\[(26a) \quad Ey_{t-1}^y - \beta Ey_{t-1}^2 = a\{Ey_{t-1}^y - \beta Ey_t^y\} + b\{Ey_{t-1}^2 - \beta Ey_{t-1}^y\}\]

From 23 and 26 and 17 it follows that

\[(27) \quad b = \frac{\begin{bmatrix} Ex_t^2 & Ey_{t-1}^y \\ Ex_{t-1}^y - \beta Ey_{t-1}^y & Ey_{t-1}^y - \beta Ey_{t-1}^2 \end{bmatrix}}{\begin{bmatrix} Ex_{t-1}^2 & Ex_{t-1}^y \\ Ex_{t-1}^y - \beta Ey_t^y & Ey_{t-1}^2 - \beta Ey_{t-1}^y \end{bmatrix}}\]

which may be expanded to give

\[(28) \quad b = \frac{\Delta_b - \beta \{Ey_{t-1}^2 Ex_t^2 - (Ex_t^y)^2\}}{\Delta - \Delta_b}\]

Using \(\frac{\Delta_b}{\Delta}\) plim \(b'\) 28 becomes

\[(29) \quad b - \beta b \text{ plim } b' = \text{ plim } b' - \frac{\beta}{\Delta} \left\{Ey_{t-1}^2 Ex_t^2 - (Ex_t^y)^2\right\}\]

From which it follows that

\[(30) \quad \text{ plim } b' = \frac{1}{1 + \beta b} \left\{b + \beta \frac{(1 - r_{xty}^2)}{(1 - r_{xty}^2)}\right\}\]

where

\[r_{xty}^2 = \frac{(Ex_t^y)^2}{Ex_t^2Ey_t^2}\]

From 30 it is clear that \(b'\) is a consistent estimate of \(b\) only if \(\beta = 0\).
Consider next the case in which $b = 0$, i.e., there is no lagged effect, then $\text{plim } b'$ becomes

$$\beta \frac{(1 - r^2_{x_t y_t})}{(1 - r^2_{x_t y_{t-1}})}$$

(31)

Since the correlation coefficients are always less than one the $\text{plim } b'$ becomes the autocorrelation coefficient multiplied by a positive constant. This constant will in general be less than one, increasing as the autocorrelation in $y$ increases and as the correlation between $x_t$ and $y_t$ decreases. It follows that the presence of sizeable autocorrelation in the errors may lead to a sizeable least squares estimate of $b$ and hence the acceptance of the lag hypothesis when in fact it is false.

When $b$ differs from zero the nature of the bias is no longer as clear. Equation 30 may be rewritten as

$$\text{plim } b' = b + \frac{\beta}{1 + \beta b} \left\{ \frac{(1 - r^2_{x_t y_t})}{(1 - r^2_{x_t y_{t-1}})} - b^2 \right\}$$

(32)

As long as the quantity within the brackets remains positive the bias has the same sign as $\beta$, but as $b$ increases the bracketed quantity decreases and may become negative. Thus, for a positive $\beta$ and any given value of $\frac{(1 - r^2_{x_t y_t})}{(1 - r^2_{x_t y_{t-1}})}$ there is a tendency for $\text{plim } b'$ to lie in the middle of the range
between zero and one since the large sample bias is positive for small $b$ and negative for large $b$.

From the above considerations it is possible to conclude that positive serial correlation in the residuals may lead to serious upward bias in the estimate of $b'$ and perhaps to the acceptance of the hypothesis II when in fact no lag is present.

Further note that just as $a'$ and $b'$ are biased estimates of $a$ and $b$ so is $u_t'$ a biased estimate of $u_t$. One component of $u_{t-1}$, namely $y_{t-1}$, is included in the estimate of $y_t$. If $y_{t-1}$ is serially correlated the observed serial correlation in $u_t'$ can be expected to be less than that suggested by $\beta$.

**Statistical Tests**

In the empirical sections which follow the common $t$ and $F$ tests will be made upon the statistics obtained from the multiple regressions. It is realized that the conditions required of the error term in order that these are precise tests may not be completely satisfied with time series data. Further, the computation of several sets of regression estimates from the same set of data means that the level of significance tests cannot be strictly applied. However, these tests do furnish considerable information on the reliability of the estimates and it is felt that the conscientious reader in attempting to evaluate the results would perform such tests even if
they were not included in the text. In the text the term "significant" will be applied to statistics which differ from the null hypothesis at the 5 per cent level when tested by ordinary methods.

The Durbin-Watson "d" (17) will be computed from the residuals of most of the regressions. As has just been argued this test can at best be considered only an approximation when applied to equations containing lagged endogenous variables. Again this does not mean that this statistic is without value, but that the bias toward non-significance should be recognized and pause taken before accepting an equation where the residuals contain evidence of serial correlation.
THE DATA

This study utilizes data from the 39 quarter periods, January, 1949, through September, 1958. When collection of data for this study was begun production and price series through the third quarter of 1958 had been revised at least once. Data on wholesale and retail margins were not available prior to 1949.

Quarterly data on marketing margins for the meats are published currently in the Marketing and Transportation situation (95). Data for pork for 1949 through 1956 are summarized in USDA Misc. pub. 711, "Pork Marketing Margins and Costs" (91). USDA Misc. pub. 710, "Beef Marketing Margins and Costs" (84) contains similar data for beef. The description of the data is taken from these publications. The wholesale margin for pork is the difference between the wholesale value at Chicago of 71 pounds of edible pork (47.4 pounds of major cuts, 8.6 pounds of minor cuts, and 15 pounds of lard) and the price of barrows and gilts per 100 pounds at Chicago. The wholesale to retail margin is the difference between the wholesale price of the major pork cuts at Chicago and the United States retail price of pork computed from the prices of the same cuts. Thus the wholesale price used in computing the retail margin differs from that used in computing the wholesale margin by the price of minor cuts and lard.

The wholesale margin for beef is the difference between
the market price of choice grade cattle and the wholesale price per 100 pounds live weight of the choice grade carcass plus the value of by-products. The live prices are obtained at several markets throughout the country and wholesale prices are obtained at New York, Chicago, Los Angeles, San Francisco, and Seattle. By-products include such items as hides and tallow and edible products such as the heart and liver.

The retail margin for choice beef is the difference between the wholesale price of choice beef at the five wholesale markets and the United States composite retail price per 100 pounds of carcass weight. The retail prices of both pork and beef are collected by the United States Bureau of Labor Statistics. Other series are compiled by the USDA.

The retail price series described above were used in the consumer demand equations. A second retail price series for pork is available which represents more cuts than the one used here (91, p. 25). Since the series differ only slightly, the series used in the margin computations was also used in the consumer demand equations. Both the margin series and the price series were deflated by the consumers price index.

Quarterly data for quantity of production, consumption, and stocks of beef and pork are published currently in the Livestock and Meat Situation. Total production is divided into commercial and farm components. In the analysis of the
marketing agencies the commercial production data are used since they represent the quantities actually passing through the marketing channels. Consumption is computed including estimates of home produced consumption. Consumption has been placed on a per capita basis through division by the population eating out of civilian food supplies. Bureau of the Census figures were interpolated to obtain estimates of population at the midpoint of the quarter.

The quarterly series of disposable personal income is the seasonally adjusted series published by the Department of Commerce. The recently revised figures published in the July, 1958, issue of the Survey of Current Business (96) were used in this study. The personal income was placed on a per capita basis and deflated by the consumers price index.

The wage series used in the retail margin equations is the wage in retail "Food and liquor stores" published currently in the Survey of Current Business (96). A similar series is published in the same source for employees in "meat product" manufacturing industries which refers primarily to wages in meat packing.
EMPIRICAL RESULTS

Consumer Demand

Since this study employs the single equation method of estimation the form of the consumer demand equations was altered from that discussed in the theoretical section. Price was designated the dependent variable and the quantities of beef and pork treated as the independent variables in the regressions.

Fox (23, pp. 30-33) has argued that yearly farm production of beef and pork can be considered largely predetermed. Most of his arguments hold with increased force for the shorter period of a quarter. The total production period for hogs approaches a year and the production period for beef is considerably longer. Farmers are able to vary production within a quarter only by feeding to heavier weights, by marketing breeding stock or by withholding stock for breeding or additional feeding. These alternatives are partially self-balancing. For example, if a high price encourages additional feeding some animals which formerly would have been marketed during the current period will be marketed during the next period. Also high prices may encourage the withholding of additional breeding stock.

Quarterly civilian consumption differs from farm production due to changes in stocks, imports and exports and
military uses. Of these, only stocks appear to be important and simultaneously determined with consumption. A later section will demonstrate that a large portion of the variation in stocks can be explained by variations in exogenous variables, but logically it is to be expected that stocks and hence consumption are simultaneously determined with price. Military takings are a function of the size of the armed forces while imports and exports are generally small relative to total production. Thus, except for stocks, consumption may be considered largely predetermined.

A slightly different formulation from that presented previously may be used to introduce lags into a demand equation which designates price the dependent variable. For example the system

(1) \[ P_{RT}^E = a P_{RT}^Q \]

(2) \[ P_{RT}^P - P_{RT-1}^P = \alpha (P_{RT}^E - P_{RT-1}^P) \]

may be used to obtain the reduced equation

(3) \[ P_{RT}^P = a \alpha Q_{RT}^P + (1 - \alpha) P_{RT-1}^P \]

The adjustment equation is given in terms of prices rather than quantities and states that the price change is proportional to the difference between the current equilibrium price and the retail price the preceding period.

A similar reduced equation may be obtained using the following specification.
\[ Q_{Rt} = b F_{Rt} \]

\[ P_{Rt} - P_{Rt-1} = \beta (Q_{PE} - Q_{P}) \]

The reduced equation in this case is

\[ (1 - b\beta)P_{Rt} = -\beta Q_{Rt} + P_{Rt-1} \]

which when estimated with \( P_{Rt} \) as the dependent variable yields the same estimates of elasticities as 3.

Equation one in Table 1 was obtained by regressing the price of pork on the per capita consumption of beef and pork, disposable personal income, time and dummy variables representing quarterly effects. Equation two is the analogous equation for beef. This type of equation has been estimated from yearly data by several agricultural economists (e.g., 23, 101). Time is introduced as an explicit variable to reflect slow changes in consumer tastes, adoption of new technology which may shift the demand, etc. Time is an unsatisfactory variable since it is merely a proxy for other variables and its use in prediction requires extrapolation. Most authors, however, have felt that coefficients obtained from demand equations (particularly for pork) including time were superior to those obtained from regressions excluding time (e.g., 101, p. 74).

Regressions one and two yield good results in the sense that a considerable portion of the variation in price is explained by the included variables and the signs of all co-
Table 1. Selected statistics from regression estimates of consumer demand equations

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>$Q_R^B$</th>
<th>$Q_R^P$</th>
<th>$Y_t$</th>
<th>Time</th>
<th>$P_{Rt-1}^B$</th>
<th>$P_{Rt-1}^P$</th>
<th>$(Q_R^P - Q_R^B)^2$</th>
<th>$C_g$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I $P_{Rt}$</td>
<td>-1.06**</td>
<td>-3.81**</td>
<td>.0071</td>
<td>-1.11*</td>
<td>(.30)</td>
<td>(.49)</td>
<td>(.0148)</td>
<td>(.046)</td>
</tr>
<tr>
<td>II $P_{Rt}$</td>
<td>-3.43**</td>
<td>-0.51</td>
<td>-.0140</td>
<td>.087*</td>
<td>(.26)</td>
<td>(.41)</td>
<td>(.0130)</td>
<td>(.040)</td>
</tr>
<tr>
<td>III $P_{Rt}$</td>
<td>-0.95**</td>
<td>-2.99**</td>
<td>.0254</td>
<td>-.118**</td>
<td>(.24)</td>
<td>(.43)</td>
<td>(.0126)</td>
<td>(.028)</td>
</tr>
<tr>
<td>IV $P_{Rt}$</td>
<td>-2.69**</td>
<td>-0.47</td>
<td>.0060</td>
<td>.082</td>
<td>(.46)</td>
<td>(.40)</td>
<td>(.0123)</td>
<td>(.043)</td>
</tr>
<tr>
<td>V $P_{Rt}$</td>
<td>-1.03**</td>
<td>-3.49**</td>
<td>.0264</td>
<td>-.138**</td>
<td>(.22)</td>
<td>(.42)</td>
<td>(.0112)</td>
<td>(.033)</td>
</tr>
<tr>
<td>VI $P_{Rt}$</td>
<td>-3.58**</td>
<td>-0.78*</td>
<td>.0251</td>
<td>.071*</td>
<td>(.46)</td>
<td>(.36)</td>
<td>(.0126)</td>
<td>(.033)</td>
</tr>
<tr>
<td>VII $P_{Rt}$</td>
<td>-1.17**</td>
<td>-4.33**</td>
<td>.0201</td>
<td>-.153**</td>
<td>(.26)</td>
<td>(.46)</td>
<td>(.0137)</td>
<td>(.043)</td>
</tr>
<tr>
<td>VIII $P_{Rt}$</td>
<td>-4.07**</td>
<td>-0.83*</td>
<td>.0312</td>
<td>.072*</td>
<td>(.28)</td>
<td>(.37)</td>
<td>(.0120)</td>
<td>(.035)</td>
</tr>
</tbody>
</table>

**Significantly different from zero at the 1 per cent level.

*Significantly different from zero at the 5 per cent level.

aInconclusive test for positive autocorrelation of residuals at 5 per cent level.

bNon-significant test for positive autocorrelation of residuals at 5 per cent level.
| \( t \) & \( C_g \) & \( \dot{Q}_{Rt} - \dot{Q}_{Rt-1} \) & \( \ddot{Q}_{Rt} - \ddot{Q}_{Rt-1} \) & \( D_1 \) & \( D_3 \) & \( D_4 \) & Constant term & \( R^2 \) & d |
|---|---|---|---|---|---|---|---|---|---|
| .275** & .94 & 3.57** & 3.78** & 87.02 & .970 & 1.64a |
| (1.07) | (.79) | (1.55) | & & & & |
| - .304** & - .019 & 1.23 & 4.04** & 4.20** & 94.83 & .968 & 1.66a |
| (1.07) | (.72) | (1.44) | & & & & |
| 5.12** & 1.45 & 10.78** & 119.80 & .853 & 1.17a |
| (1.26) | (0.85) | (1.85) | & & & & |
| 1.01 & 3.64** & 3.04** & 102.67 & .953 & 1.40a |
| (1.07) | (.73) | (.50) | & & & & |
| 3.57** & .88 & 6.12** & 51.73 & .910 & 1.74b |
| (1.06) | (.69) | (1.83) | & & & & |
| .54 & 2.92** & 2.48 & 87.75 & .958 & 1.51a |
| (1.06) | (.79) | (1.55) | & & & & |
| 4.44** & .75 & 7.46** & 71.16 & .932 & 1.56a |
| (1.06) | (.61) | (1.69) | & & & & |
| - .254** & - .019 & 1.23 & 4.04** & 4.20** & 94.83 & .968 & 1.66a |
| (1.07) | (.72) | (1.44) | & & & & |
| * & .324 & 5.86** & .56 & 9.42** & 111.31 & .907 & 1.12a |
| (1.05) | (1.00) | (2.52) | & & & & |

* t level.  
** t level.
coefficients agree with a priori expectations. However, the coefficients for income in both equations are small relative to their standard errors as is the coefficient for pork quantity in the beef regression. The d statistics, although in the inconclusive range, are suggestive of positive serial correlation in the residuals.

Regression equations three and four were obtained by adding the respective lagged prices to regressions one and two. The addition of lagged price to the pork equation significantly reduced the variance of the residuals, the F value for 1 and 29 degrees of freedom being 18.24; while the similar F value of 3.59 for the beef regression indicated that lagged price did not significantly improve the fit of the equation. The evidence of positive serial correlation in the residuals of the pork equation is considerably reduced by the addition of lagged price. This is also true to a lesser degree for the beef equation.

When residuals from pork equation 3 were plotted against the quantity of pork the residuals tended to fall in a "U" indicating the presence of curvilinearity in the regression of price on quantity. Curvilinearity can be introduced into the equation either by converting the variables to logarithms or by introducing a squared term. A squared term was introduced into the equation since this involved less computational expense and since there was little evidence of curvilinearity
in the other partial regressions.

The statistics for this regression are given on line five of the table. As the residuals of the previous regression suggested, the fit is significantly improved by the addition of the squared term.

It is noteworthy that the coefficient of lagged price was reduced over one-fourth by the addition of the squared term. As Cochran and Orcutt (15, p. 36) have pointed out the application of the incorrect functional form to serially correlated time series will introduce serial correlation into the residuals. In the section on statistical estimation contained in this study it was pointed out that the presence of such correlation in the residuals would tend to bias the coefficient of the lagged endogenous variable toward significance and further that it was possible that little evidence of serial correlation would remain in the residuals. These effects are aptly demonstrated by the two pork regressions. The d statistics of 1.74 obtained from regression three is non-significant and hence only mildly suggestive of serial correlation. The reduction in the coefficient of lagged price obtained by the introduction of the quadratic term indicates that lagged price had "picked up" the serial correlation resulting from the incorrect functional form of the previous regression.

When the residuals from beef equation 2 were plotted
against the quantity of beef there was little evidence of curvilinearity. One important characteristic of the residuals was observable however. The four quarters from the second quarter of 1950 through the first quarter of 1951 had large positive deviations as did the four quarters of 1952. The three intervening quarters showed sizeable negative deviations. Apparently the ceiling prices imposed by the OPS in May of 1951 held beef prices below the level indicated by beef and pork supplies. Prices remained at ceiling levels until 1952 and then fell below the ceiling as supplies increased. Thus it appears that the last three quarters of 1951 should be removed from the regression if unbiased estimates of the demand relationship are to be obtained. Rather than recompute the sums of squares and cross-products with these observations deleted it was decided to include a variable to represent the effects of the price ceilings. This variable, denoted by Cg in the table, is equal to consumption during the last three quarters of 1951 and is zero in all other periods. Comparison of beef regressions four and six indicates that the regression is improved by taking into account the conditions existing in 1951. Not only is the correlation significantly improved when tested by the F test but the coefficients for pork quantity and income increased in value becoming more comparable with the statistics obtained in the pork regression. The coefficient for lagged price
decreased, indicating that it was biased by the non-independence of the residuals introduced by the price ceilings. Finally the evidence of serial correlation as measured by the d statistic is less in regression six than in the previous beef regressions.

Regression equations five and six were recomputed replacing lagged prices with the respective lagged quantities. In an attempt to reduce the intercorrelation among the variables the change in consumption \((Q_{Rt} - Q_{Rt-1})\) was used in the regression rather than lagged consumption \((Q_{Rt-1})\). The results of these regressions are given on lines seven and eight of Table 1.

In neither equation is the coefficient for lagged quantity greater than its standard error. In the pork equation lagged quantity enters with a negative sign while lagged quantity enters the beef equation with a positive sign. It is interesting to note that the evidence of serial correlation in the residuals is much greater in the pork equation containing lagged quantity than in the equation containing lagged price. This suggests that the significance of the coefficient of lagged price is at least partially due to autocorrelation in the residuals.

The dummy variables representing unexplained quarterly effects were constructed with the second quarter assigned a zero value. Thus \(D_1\) represents the deviation of the first
quarter from the second quarter, $D_3$ the deviation of the third quarter from the second quarter, and $D_4$ the deviation of the fourth quarter from the second quarter, where the constant term of the regression gives the intercept value for the second quarter.

The results indicate that there is a seasonal rise in the demand for pork during the fourth and first quarters relative to the second and third quarters, with the peak demand occurring during the fourth quarter. The demand for choice beef appears to be greatest during the third and fourth quarters. Part of the increase in demand associated with the third quarter is probably due to the smaller importance of choice beef relative to all beef during this quarter.

The price flexibility and elasticity estimates as computed from the various regression equations are summarized in Table 2. All computations were made at the mean where the means were as follows: pork quantity, 16.47; beef quantity, 18.38; pork price, 51.73; beef price, 52.56; and income, 1413.

In those equations which contain lagged price the long

---

1Price flexibility with respect to quantity is defined as $\frac{\partial P}{\partial Q} \cdot \frac{Q}{P}$ and price flexibility with respect to income as $\frac{\partial P}{\partial Y} \cdot \frac{Y}{P}$. From these definitions it follows that price elasticity is the reciprocal of the price flexibility with respect to quantity and that income elasticity is the product of price elasticity and price flexibility with respect to income.
<table>
<thead>
<tr>
<th>Regression number and commodity</th>
<th>Price flexibility w.r.t. quantity</th>
<th>Price elasticity</th>
<th>Price flexibility w.r.t. income</th>
<th>Income elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short run</td>
<td>Long run</td>
<td>Short run</td>
<td>Long run</td>
</tr>
<tr>
<td>I Pork</td>
<td>1.21</td>
<td>1.21</td>
<td>.82</td>
<td>.82</td>
</tr>
<tr>
<td>III Pork</td>
<td>.95</td>
<td>1.67</td>
<td>1.05</td>
<td>.60</td>
</tr>
<tr>
<td>V Pork</td>
<td>1.11</td>
<td>1.60</td>
<td>.90</td>
<td>.62</td>
</tr>
<tr>
<td>VII Pork</td>
<td>1.28</td>
<td>1.38</td>
<td>.78</td>
<td>.73</td>
</tr>
<tr>
<td>II Beef</td>
<td>1.20</td>
<td>1.20</td>
<td>.83</td>
<td>.83</td>
</tr>
<tr>
<td>IV Beef</td>
<td>.94</td>
<td>1.24</td>
<td>1.06</td>
<td>.80</td>
</tr>
<tr>
<td>VI Beef</td>
<td>1.25</td>
<td>1.44</td>
<td>.80</td>
<td>.68</td>
</tr>
<tr>
<td>VIII Beef</td>
<td>1.42</td>
<td>1.42</td>
<td>.70</td>
<td>.71</td>
</tr>
</tbody>
</table>
run price flexibility is greater than the short run and hence, the price elasticity is less in the long run. Such results are contrary to most of the arguments presented on the time path of elasticity wherein it is generally concluded that elasticity increases with time. However, the positive coefficient for lagged price and the corresponding greater price elasticity in the short run is consistent with inelastic price expectations. If consumers believe that a current price fall will be followed by a price rise they may tend to enlarge current consumption at the expense of future purchases. Expectations of this type are quite realistic in the case of pork which is subject to recurring seasonality of prices as well as recurring cyclical price movements. The results should be considered only suggestive since as has been pointed out, it is impossible to answer a priori the question: does the addition of lagged price to the equation improve the fit because of correlated errors in the residuals, or are correlated errors in the residuals of equations which do not contain lagged price caused by the presence of distributed lags?

The equations containing lagged quantity present little evidence of a difference between the long and short run elasticity. They yield estimates of price elasticity of about .75 for pork and about .70 for beef, and estimates of income elasticity of about .4 for pork and .6 for beef. The correlation of time and income results in large standard errors for
these estimates. In fact the estimate for pork does not differ significantly from zero.

Estimates of price and income elasticities obtained in several studies utilizing yearly data are shown in Table 3. An attempt was made to choose estimates obtained by different methods and from data for different time periods, mostly pre-war, but no attempt was made to include a wide range of estimates. Perhaps, therefore, the consistency of the estimates of price elasticity is somewhat surprising.

The estimates of elasticity obtained in this study are not strictly comparable with those of Table 3 since the linear form was used in this study and hence the derived elasticity is not constant throughout the range of price and quantity. The estimates of long run price elasticity obtained in this study are generally more inelastic than those presented in the table, with the exception of the Maki estimate of the price elasticity for pork. The use of quantity as the dependent variable and prices as independent variables tends to produce estimates which are more inelastic than the procedure employed in this study. It is, however, interesting to note the similarity between the Maki estimate and the estimate of long run elasticity obtained in equation five of this study.
Table 3. Estimates of price and income elasticities obtained in selected studies

<table>
<thead>
<tr>
<th>Source</th>
<th>Form of data</th>
<th>Method</th>
<th>Period studied</th>
<th>Pork Price elasticity</th>
<th>Pork Income elasticity</th>
<th>Beef Price elasticity</th>
<th>Beef Income elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fox (23)</td>
<td>First differences</td>
<td>Least squares price dependent</td>
<td>1922-41</td>
<td>0.86</td>
<td>0.77</td>
<td>0.94</td>
<td>0.83</td>
</tr>
<tr>
<td>Working (101)</td>
<td>Logarithms</td>
<td>Least squares price dependent</td>
<td>1922-41</td>
<td>0.94</td>
<td>--</td>
<td>1.10</td>
<td>--</td>
</tr>
<tr>
<td>Nordin, Judge and Wahby (61)</td>
<td>Logarithms</td>
<td>Simultaneous equations just identified</td>
<td>1922-41</td>
<td>0.91</td>
<td>0.76</td>
<td>0.77</td>
<td>0.65</td>
</tr>
<tr>
<td>Wallace and Judge (97)</td>
<td>Logarithms</td>
<td>Simultaneous equations limited information</td>
<td>1925-41, 1947-55</td>
<td>0.98</td>
<td>0.86</td>
<td>0.87</td>
<td>0.59</td>
</tr>
<tr>
<td>Maki (50)</td>
<td>First differences</td>
<td>Least squares quantity dependent</td>
<td>1922-41, 1949-56</td>
<td>0.61</td>
<td>0.74</td>
<td>0.94</td>
<td>0.63</td>
</tr>
</tbody>
</table>
Retail Margin

The retail margin was regressed on the change in wholesale prices, wage rates in food retailing, the wholesale price, the lagged margin and quarter dummies. Results are presented in Table 4. The coefficient for the wholesale price of pork was negative and small (less than its standard error) and its deletion did not change either the other coefficients or the $R^2$ noticeably. Therefore it is not included in the equation shown in Table 4. The coefficient for the beef wholesale price contributed significantly to the beef margin regression however, indicating some tendency toward a percentage markup in beef.

In both equations the change in the own wholesale price exerts a significant negative effect upon the margin. Thus there appears to be a definite delay by retailers before changing retail prices in response to changes in wholesale prices.

The change in the wholesale price of the competing commodity tended to exert a positive influence on margins. Apparently the change in wholesale price of one meat affects the retail price of both.

The coefficient for lagged margin was positive in both equations, though non-significant in the case of pork, suggesting that there is some lag in margin adjustment.

The coefficient for wages was positive in both equations.
Table 4. Selected statistics from regression estimates of retail margin errors

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>$\Delta P_{Wt}^B$</th>
<th>$\Delta P_{Wt}^P$</th>
<th>$D_1$</th>
<th>$D_3$</th>
<th>$D_4$</th>
<th>Wages</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>$M_{Rt}^P$</td>
<td>-.078</td>
<td>-.157*</td>
<td>.184</td>
<td>.559</td>
<td>.770</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(.046)</td>
<td>(.042)</td>
<td>(.32)</td>
<td>(.29)</td>
<td>(.46)</td>
</tr>
<tr>
<td>II</td>
<td>$M_{Rt}^B$</td>
<td>-.217**</td>
<td>.129**</td>
<td>-.428</td>
<td>-.324</td>
<td>.641</td>
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<tr>
<td></td>
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<td>(.057)</td>
<td>(.050)</td>
<td>(.38)</td>
<td>(.35)</td>
<td>(.57)</td>
</tr>
<tr>
<td>III</td>
<td>$M_{Rt}^B$</td>
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<td>.149**</td>
<td>-.119</td>
<td>.209</td>
<td>.708</td>
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<td>(.046)</td>
<td>(.039)</td>
<td>(.30)</td>
<td>(.29)</td>
<td>(.43)</td>
</tr>
</tbody>
</table>

**Significantly different from zero at the 1 per cent level.

*Significantly different from zero at the 5 per cent level.

aNon-significant test for positive autocorrelation of residuals at 5%.
of retail margin equations

and their standard errors

<table>
<thead>
<tr>
<th>Year</th>
<th>Wages</th>
<th>$M_{Rt-1}^B$</th>
<th>$M_{Rt-1}^P$</th>
<th>$F_{Wt}^B$</th>
<th>$\Delta F_{Wt}^B$</th>
<th>Constant term</th>
<th>$R^2$</th>
<th>d</th>
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<tr>
<td>1970</td>
<td>4.335*</td>
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<td>3.27</td>
<td>.753</td>
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</tr>
<tr>
<td>1976</td>
<td>(1.92)</td>
<td>(.14)</td>
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<tr>
<td>1971</td>
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<td>(.029)</td>
<td>(.047)</td>
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<td></td>
<td></td>
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</tbody>
</table>

^a t level.

^b t level.

of residuals at 5 per cent level.
However, it is probable that time or income would have served almost as well to indicate a widening of retail margins over time. It is impossible to separate the price and quantity components of the margin. Generally speaking, more services such as wrapping and displaying are now performed by retailers and this increase in services is confounded with increasing wages and increasing efficiency in retailing.

When the residuals of the beef margin equation were plotted against the change in the wholesale price of beef it was evident that the slope of the regression was different for the third and fourth quarters as opposed to the first and second quarters. Therefore the following variable was added to the equation:

\[
\begin{align*}
\left[ \Delta F^B_{Wt} \right]' &= \Delta F^B_{Wt} \\
&= -\Delta F^B_{Wt}
\end{align*}
\]

First and second quarter

Third and fourth quarter

The statistics for this regression are given on line three of the table. Thus the coefficient for \( \Delta F^B_{Wt} \) becomes \( -.282 + .222 = -.060 \) for the first and second quarter and \( -.282 - .222 = -.504 \) for the third and fourth quarters. Retailers apparently absorb about one-half of the wholesale price change in choice beef during the third and fourth quarters and only six per cent of the change during the first and second quarters.

One possible explanation of this difference lies in the
relative importance of choice beef as a proportion of total meat. During the third quarter large quantities of grass fed cattle which grade below choice are marketed. The proportion of choice beef to all beef then increases from the third to the fourth quarter, but pork supplies reach their seasonal peak during the fourth quarter. During these periods when choice beef is of less relative importance there is less pressure on retail prices to follow wholesale prices. Changes in retail prices of choice beef will be influenced more by changes in prices of competing meats than by changes in the wholesale price of choice beef.

Ignoring variables except the own price it is possible to rewrite the equations of Table 4 as follows:

\[
P^B_{Rt} = .84 P^P_{Wt} - .01 P^P_{Wt-1} + .17 P^P_{Rt-1}
\]

\[
P^P_{Rt} = 1.02 P^P_{Wt} - .27 P^P_{Wt-1} + .33 P^P_{Rt-1}
\]  
First and second quarters

\[
P^B_{Rt} = .58 P^P_{Wt} + .17 P^P_{Wt-1} + .33 P^P_{Rt-1}
\]  
Third and fourth quarters

Thus, when the retail price is expressed as a function of the current wholesale prices and lagged prices, the lags both in retail price and wholesale price appear to be important in beef while only the lagged value of the retail price appears important in the pork equation.

The Durbin-Watson statistics were non-significant for
all equations giving no reason to reject the hypothesis of independent residuals.

None of the quarter dummies exceeded twice their standard errors. However it appears other things being equal that the pork margin tends to be greater during the third and fourth quarters relative to the first and second quarters. The quarter dummies in the beef equation suggest that the other variables included do not effectively explain the level of the margin in the fourth quarter.

Storage Stocks

Regression equations one and four in Table 5 express the change in stocks during the current quarter as a function of the changes in production of beef and pork from last period to this period, beginning stocks, and quarter dummies. The change in production of both beef and pork exerts a significant effect upon beef stocks while the change in beef production has little apparent effect upon the change in pork stocks. When the residuals from the beef storage regression were plotted against $\Delta Q^B_{Tt}$ there was evidence that the slope of the regression for the fourth quarter differed from that in other quarters. Therefore the following variable was constructed and added to the regression:
Table 5. Selected statistics from regression estimates of storage equations

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>$\Delta_{Q_{st}}$</th>
<th>$\Delta_{Q_{st-1}}$</th>
<th>$B_{st-1}$</th>
<th>$P_{st-1}$</th>
<th>$B_{st-2}$</th>
<th>$P_{st-2}$</th>
<th>$\Delta F$</th>
</tr>
</thead>
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<td>I $\Delta_{st}$</td>
<td>.135** (.029)</td>
<td>.061** (.022)</td>
<td>-.205** (.078)</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>II $\Delta_{st}$</td>
<td>.131** (.026)</td>
<td>.051** (.021)</td>
<td>-.231** (.072)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III $\Delta_{st}$</td>
<td>.136** (.025)</td>
<td>.048* (.020)</td>
<td>-.044 (.116)</td>
<td>-.229</td>
<td></td>
<td>(.115)</td>
<td></td>
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<tr>
<td>IV $\Delta_{st}$</td>
<td>.001 (.078)</td>
<td>.349** (.056)</td>
<td>-.017 (.065)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V $\Delta_{st}$</td>
<td>-.076 (.068)</td>
<td>.226** (.114)</td>
<td>.108 (.103)</td>
<td>-.328**</td>
<td>21.26**</td>
<td>(.69)</td>
<td></td>
</tr>
<tr>
<td>VI $\Delta_{st}$</td>
<td>-.092 (.063)</td>
<td>.210** (.058)</td>
<td>.054 (.106)</td>
<td>-.297**</td>
<td>19.37**</td>
<td>(.095)</td>
<td>(.64)</td>
</tr>
</tbody>
</table>

**Significantly different from zero at the 1 per cent level.

*Significantly different from zero at the 5 per cent level.

^Inconclusive test for positive serial correlation at 5 per cent level.

^Non-significant test for positive serial correlation at 5 per cent level.

^Significant test for positive serial correlation at 1 per cent level.
<table>
<thead>
<tr>
<th>ΔF</th>
<th>(ΔQ_E/H)</th>
<th>(ΔQ_H/F)</th>
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<th>D_2</th>
<th>D_3</th>
<th>D_4</th>
<th>Constant term</th>
<th>R^2</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.51**</td>
<td>-10.96</td>
<td>43.55</td>
<td>12.25</td>
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<td>1.27^a</td>
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<tr>
<td>(.014)</td>
<td>(.012)</td>
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<tr>
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<tr>
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<td>67.37</td>
<td>.967</td>
<td>2.15^b</td>
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<tr>
<td>(6.69)</td>
<td>(21.34)</td>
<td>(31.95)</td>
<td>(70.22)</td>
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<tr>
<td>19.37**</td>
<td>.071**</td>
<td>191.31**</td>
<td>29.00</td>
<td>.973</td>
<td>1.56^a</td>
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<tr>
<td>(6.14)</td>
<td>(.027)</td>
<td>(34.52)</td>
<td>(65.69)</td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

Notes:
- **t level.
- *t level.
- rel.
First, second and third quarters

\[ \Delta Q^B_{Pt} = -3 \Delta Q^B_{Pt} \]  
Fourth quarter

This regression is numbered two in the table. Ignoring the other variables, regression two yields the following estimate for the regression coefficients of \( \Delta Q^B_{Pt} \); \( \Delta s^B_t = 0.093 \Delta Q^B_{Pt} \) for the first, second and third quarters, and \( \Delta s^B_t = 0.245 \Delta Q^B_{Pt} \) for the fourth quarter.

A priori it was expected that while beginning stocks would be positively correlated with ending stocks the coefficient would be less than one. Thus the regression coefficients obtained with the change in stocks as the dependent variable were expected to be negative. The results of beef regression agree with this reasoning, the coefficient for beginning stocks being -0.23, but for pork the coefficient was near zero. Either beginning stocks of pork exert no influence on the change in stocks, or this simple model produces a bias in the coefficient for lagged stocks. The presence of significant serial correlation in the residuals supports the latter hypothesis.

Regression equations three and five represent the expectational model discussed earlier. Thus the pork equation is:

\[ s^P_t = (2 - \alpha - \beta) s^P_{t-1} - (1 - \alpha)(1 - \beta) s^P_{t-2} \]

\[ - \beta b_0(1 - \alpha) \Delta Q^B_{Ft} - \beta b_1(1 - \alpha) \Delta Q^P_{Ft} + \beta b_1 \gamma \Delta F \]
where $\beta$ represents the technological rate of adjustment in stocks, $\alpha$ represents the rate of adjustment in expectations, and the $b$'s represent the influence of the expected change in quantity on equilibrium stocks. The farrowing variable, $\Delta F$, included in the pork equation, is the difference between the fall pig crop and the spring pig crop (in millions of pigs) measured from its mean value. It enters the regression during the period of accumulation, the fourth and first quarters. Stocks lagged two periods and the farrowing variable both significantly improved the fit of the pork equation. The $F$ value for the reduction due to the addition of these two variables is 11.6 which is highly significant for 2 and 29 degrees of freedom. Also the "d" statistic for this regression falls in the non-significant range.

The residuals of this regression indicated that the slope of the partial regression of stocks on production change differed between the second quarter and the remaining quarters. Therefore the variable

$$\left[\Delta Q^P_{Pt}\right]' = -2 \Delta Q^P_{Pt} \quad \text{Second quarter}$$

$$= \Delta Q^P_{Pt} \quad \text{First, third and fourth quarters}$$

was added to the regression. As the results given on line six of the table indicate, the fit is significantly improved by the addition of the slope dummy. The difference in slope associated with the second quarter is probably due to the
fact that this is primarily a holding period for stocks. Although stocks are generally decreased moderately during this time the major portion of the stock liquidation occurs during the third quarter when prices are at their seasonal high. Therefore a greater decrease in production is required to move stocks during the second quarter which is generally followed by increasing prices than during the third quarter which is followed by decreasing prices.

The $F$ value for the reduction in the sum of squares due to the addition of $s^B_{t-2}$ to the beef equation is 4.22 which is just beyond the 5 per cent point of $F$ for one and 29 degrees of freedom. The addition of the variable resulted in less evidence of serial correlation, the Durbin-Watson $d$ being in the non-significant range rather than in the inconclusive range.

The addition of stocks lagged two periods to the equations improves the predictive ability of the equations, but as before the interpretation of the coefficients is difficult. As has been shown $s^P_{t-2}$ will enter the equation under either the expectation assumptions or the assumption of correlated residuals.

Equations three and six will each yield two sets of estimates for the $\alpha$ and $\beta$ of the original system, since the coefficients of $s_{t-1}$ and $s_{t-2}$ form identical quadratics in $\alpha$ and $\beta$. Estimates of $\alpha$ and $\beta$ obtained from the coefficients
of \( s_{t-1}^P \) and \( s_{t-2}^P \) in the pork equation are in fact compound imaginary numbers. However the imaginary portion of the numbers is small and very minor changes in the coefficients of either \( s_{t-1} \) or \( s_{t-2} \) would yield estimates of \( \alpha \) and \( \beta \) in the neighborhood of 0.5. The quadratic associated with the beef equation is almost a perfect square and also yields estimates of \( \alpha \) and \( \beta \) of about 0.5. If the original model and the assumption of independent errors is accepted the two equations yield an estimate of the coefficient of expectation in the expectational equations of approximately .5 and an estimate of the rate of adjustment of about .5 for both beef and pork.

In addition to the regressions shown in the table, regression five was computed with time as an added variable. The coefficient for time was less than its standard error and its inclusion did not change any of the other coefficients significantly.

Equations one and four were also fitted with the beginning stocks of the competing commodity as an additional variable. The coefficient was positive in both instances but did not add significantly to either equation. It might be that stocks of the competing commodity should enter with a positive sign during periods of depletion (since the pressure to liquidate (say) pork stocks may result in beef stocks being held longer) and with a negative sign during periods of accumulation (since large stocks of the competing commodity will
tend to lower the expected price rise). However a variable of this type was not tried in the regression.

The coefficients for the dummy variables in the pork equation indicate that there is an accumulation during the first quarter and a depletion during the third quarter which is not explained by variation in the other variables. Only the first quarter dummy differs significantly from zero. Most of the stock accumulation occurs during the first part of the first quarter and, in fact, stocks may decrease during March. Hence the change in production from the fourth to the first quarter does not fully reflect the change within the quarter which may explain the significance of the first quarter dummy. The second quarter value has been assigned the arbitrary zero value and the values in the table are deviations from the second quarter rather than from the yearly average. The coefficient for the fourth quarter is positive but the correlation with $\text{Opt}_t$ results in a large standard error for the coefficient.

Only the fourth quarter dummy is consistently sizeable for beef indicating an accumulation not explained by the other variables. If $s_{t-2}^B$ is not included in the regression the first quarter dummy also differs significantly from zero.

In interpreting the multiple correlation coefficients of the table it should be remembered that a large portion of the variation in the change in stocks can be explained by
quarter dummy variables alone. For beef the dummy variables alone explain about 81 per cent of the variation and the other variables explain about two-thirds of the remaining variation while for pork the dummy variables explain about 75 per cent of the total variation and the other variables explain about 90 per cent of the remaining variation. On the other hand replacing the change in stocks by ending stocks as the regression would increase the $R^2$ values.

Farm to Wholesale Margin

Lines one and two of Table 6 present the statistics obtained by regressing the wholesale margin on the change in farm marketings of beef and pork, the wholesale price, and margin lagged one period. In the case of beef an additional variable has been included to represent the per cent of all beef which is choice beef. This variable, denoted by Ch in the table, is constructed by subtracting cows and stags as a per cent of all federally inspected slaughter from the per cent of steers grading prime or choice at the three largest markets (Chicago, Omaha, and Sioux City). In these regressions all variables were first adjusted by the quarter means. That is, the means of each series were computed by quarters and these means subtracted from the respective quarter values. This procedure yields results equivalent to the inclusion of dummy variables in the regression. Values for the quarter
Table 6. Selected statistics from regression estimates of wholesale margin equations

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>$B_{Wt-1}$</th>
<th>$P_{Wt-1}$</th>
<th>$\Delta Q_{Fr}$</th>
<th>$\Delta P_{Fr}$</th>
<th>$P_{Wt}$</th>
<th>$P_{Fr}$</th>
<th>ch</th>
<th>$\Delta Q_{Fr-1}$</th>
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<td>(.000344)</td>
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<td>.000831**</td>
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<td>(.0079)</td>
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</tbody>
</table>

**Significantly different from zero at the 1 per cent level.

*Significantly different from zero at the 5 per cent level.

^Non-significant test for autocorrelation in the residuals at the 5 per cent level.

^Inconclusive test for autocorrelation in the residuals at the 5 per cent level.
<table>
<thead>
<tr>
<th>$\Delta P_{Ft-1}$</th>
<th>$\Delta Q_{Ft-1}$</th>
<th>$P_{wt-2}$</th>
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<th>$D_2$</th>
<th>$D_3$</th>
<th>$D_4$</th>
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<td>(.0415)</td>
<td>(.0415)</td>
<td>(.0415)</td>
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</tbody>
</table>

significant level.

 significant level.
dummies have been computed using the quarter means but standard errors for these estimates have not been computed.

The variable used to represent the proportion of choice cattle in all marketings appears to be the most important explanatory variable in the beef regression. This variable indicates that as the per cent of choice cattle increases the margin increases. Apparently the wholesale margin tends to be highest on the type of cattle in greatest relative supply.

The change in farm production of pork exerts a positive and significant effect upon the pork wholesale margin, but the coefficient for the change in beef production obtained in the beef regression, although positive, is only approximately equal to its standard error.

In neither regression does the change in the supply of the competing meat show a significant effect upon the margin, and in the pork equation the negative sign on \( \Delta Q_t \) is opposite to that expected \textit{a priori}. Regressions three and four were obtained by deleting the change in supply of the competing commodity from the regression. It is easily seen that both the coefficients of the remaining variables and the multiple correlation are altered little by the deletion.

The coefficients for the wholesale price are negative in both equations suggesting that changes in farm prices exceed slightly changes in wholesale prices. However neither of the coefficients exceeds twice its standard error.
The margin lagged one period is an important explanatory variable, the coefficients being positive and significantly different from zero in both equations. In particular the pork regression suggests that there is a considerable lag in margin adjustment.

In addition to the results presented in the table, equations similar to one and two containing as an additional variable the wages in meat processing industries were fitted. In neither case did the addition of wages significantly improve the fit. Further the coefficient for wages was positive in the pork equation and negative in the beef equation.

Regressions five and six represent the empirical application of the expectational model discussed in the theory section. Apparently this model is not a correct representation of margin behavior. The fit of the regressions is little better than that obtained by the simpler models. Further the signs of some of the coefficients do not agree with the restrictions imposed by the model. The lagged production change should enter with sign opposite that of the current production change while margin lagged two periods should enter with sign opposite that of margin lagged one period. Thus, the coefficient for margin lagged two periods in the pork equation and production change lagged one period in the beef equation possess signs opposite the a priori restrictions.

Price changes of an individual meat at the wholesale
level may be induced either by an increase in the supply at wholesale of this meat or by a shift in the price quantity relationship (a shift in demand). These shifts may arise from such sources as changes in prices of competing goods or changes in disposable income. Changes in wholesale prices arising in this manner can be called changes from outside. In an attempt to discover if there is a lag in the adjustment of farm prices to wholesale price changes from outside, the change in wholesale price was added to regressions three and four. The coefficient for the change in the wholesale price of beef is positive and significant indicating a lag before price changes from above are reflected in farm prices. However, the coefficient for the change in the wholesale price of pork is negative and less than its standard error. Apparently the wider fluctuations in pork production mean that most price changes are associated with changing supplies and/or the farm price of pork adjusts more rapidly than the farm price of beef to changes in demand.

It is possible to write beef equation eight and pork equation four in terms of prices as follows:

$$P^B_{Ft} = .92 P^B_{Wt} - .19 P^B_{Wt-1} + .23 P^B_{Ft-1} - .00115 \Delta Q^B_{Tt}$$

$$P^P_{Ft} = 1.03 P^P_{Wt} - .46 P^P_{Wt-1} + .46 P^P_{Ft-1} - .00089 \Delta Q^P_{Tt}$$
The Completed Model

A set of estimates for the eight equations of the model have been summarized in Table 7. The eight variables listed in the left part of the table are considered endogenous to the system. The remaining variables are lagged values of the endogenous variables and those treated as exogenous to the system. All equations have been normalized on one of the endogenous variables. Note that except for one coefficient the model as illustrated here satisfies the conditions required of a recursive system.

If in a recursive system the errors are independent among equations and independent of the endogenous variables, the theorems of Wold (99) apply and least squares yields unbiased estimates of the coefficients.

It is doubtful if these conditions are fully met in the model under consideration. For example, the variables influencing the wholesale margin but not included in that equation may also enter the storage equation and perhaps the retail margin equation as well.

Table 7 aids in evaluating the possible presence of least squares bias in the estimates. The storage equation contains only predetermined variables. Hence the coefficients of these variables should be unbiased. The high correlations obtained in the consumer demand regressions and the relatively large portion of the variation in storage explained by pre-
Table 7. Estimated coefficients for the model of the beef and pork economy

<table>
<thead>
<tr>
<th>Endogenous variables</th>
<th>( B_s^t )</th>
<th>( B_{Pt}^t )</th>
<th>( B_{Pt}^t )</th>
<th>( B_{Pt}^t )</th>
<th>( B_{Pt}^t )</th>
<th>( Q_{Pt}^t )</th>
<th>( Q_{Pt}^t )</th>
<th>( Q_{Pt}^t )</th>
<th>( Q_{Pt}^t )</th>
<th>( P_{Pt}^t )</th>
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<td></td>
<td></td>
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<td>.05*</td>
<td>-.14**</td>
<td>-.05*</td>
<td>.96**</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td></td>
<td>-1</td>
<td></td>
<td></td>
<td></td>
<td>-.09</td>
<td>.24**</td>
<td>.09</td>
<td>-.24**</td>
<td>1.05**</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>+3.58**(^a)</td>
<td>+.78*</td>
<td>-1</td>
<td></td>
<td></td>
<td>(-3.58)**</td>
<td>-.78*</td>
<td>(\frac{-3.58)}{N})**</td>
<td>(\frac{-.78)}{N})**</td>
<td>(\frac{-3.58)}{N})**</td>
<td>(\frac{-.78)}{N})**</td>
</tr>
<tr>
<td>IV</td>
<td>(\frac{+1.03)}{N})**</td>
<td>(\frac{+3.49)}{N})**</td>
<td>-1</td>
<td></td>
<td></td>
<td>(-1.03)**</td>
<td>(\frac{-3.49)}{N})**</td>
<td>(\frac{-1.03)}{N})**</td>
<td>(\frac{-3.49)}{N})**</td>
<td>(\frac{-1.03)}{N})**</td>
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</tr>
<tr>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.72**</td>
<td>-1(^c)</td>
<td>-.26**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.19**</td>
<td>-.10</td>
<td>-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>.92(^d)</td>
<td>-1</td>
<td>.00115(^*)</td>
<td>.00115(^*)</td>
<td>(P_{Pt}^t)</td>
<td>(P_{Pt}^t)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIII</td>
<td>1.03(^d)</td>
<td>-1</td>
<td>-.00089(^**)</td>
<td>.00089(^**)</td>
<td>(P_{Pt}^t)</td>
<td>(P_{Pt}^t)</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

\(^a\) Original coefficient differed significantly from zero at the 1 per cent level.

\(^b\) Original coefficient differed significantly from zero at the 5 per cent level.

\(^c\) N denotes civilian population.

\(^d\) The equation also contains the squared term: \(0.22 \left( \frac{Q_{Pt}^t + s_{Pt}^t - s_{Pt}^t}{N} - 16.5 \right)^2 \)

\(^e\) Coefficients are those obtained for the third and fourth quarters.

\(^f\) The wholesale price in this instance is expressed on a liveweight basis where 100 pounds liveweight equals 71 pounds carcass weight for beef. Further the wholesale price in these equations includes a by-
### Predetermined variables

<table>
<thead>
<tr>
<th>( B_{t-1} )</th>
<th>( Q^p_{t-1} )</th>
<th>( s^B_{t-1} )</th>
<th>( s^P_{t-1} )</th>
<th>( Y_t )</th>
<th>Time</th>
<th>( P^B_{w_{t-1}} )</th>
<th>( P^P_{w_{t-1}} )</th>
<th>Wages</th>
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<tr>
<td>.14**</td>
<td>-.05*</td>
<td>.96**</td>
<td>-.23*</td>
<td>( s^B_{t-2} )</td>
<td>(-.04^* )</td>
<td>( \Delta Q^B_{F_t} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>.09</td>
<td>-.24**</td>
<td>1.05**</td>
<td>-.30**</td>
<td>( s^P_{t-2} )</td>
<td>19.37**</td>
<td>( \Delta F )</td>
<td>(.07^{**} )</td>
<td>( \Delta Q^P_{F_t} )</td>
</tr>
<tr>
<td>(-3.58^{**} )</td>
<td>(-.78^N )</td>
<td>(.025 )</td>
<td>.07*</td>
<td>.13</td>
<td>( P^B_{R_{t-1}} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(-1.03^{***} )</td>
<td>(-3.49^{**b} )</td>
<td>(.026 )</td>
<td>(-.14^{**} )</td>
<td>.31**</td>
<td>( P^P_{R_{t-1}} )</td>
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<td></td>
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<tr>
<td>(-.57^{**} )</td>
<td>-.29**</td>
<td>.26**</td>
<td>(-12.91^{**} )</td>
<td>( P^B_{R_{t-1}} )</td>
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<tr>
<td>(-.20^{**} )</td>
<td>.10</td>
<td>.01</td>
<td>(-5.16^* )</td>
<td>( P^P_{R_{t-1}} )</td>
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<tr>
<td>.015*</td>
<td>(-.19^* )</td>
<td>(.28^* )</td>
<td>(-.0358^{**} )</td>
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<td></td>
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<tr>
<td>.00089**</td>
<td>(.16^{**} )</td>
<td>( P^E_{F_{t-1}} )</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

\( \Delta \) is where 100 pounds liveweight equals 59 pounds carcass weight for pork and 100 pounds liveweight. These equations include a by-product allowance.
determined variables leads one to expect little bias in the coefficients of the demand equations.

On the other hand the poorer correlation of the retail margin regressions and the inclusion of current wholesale prices among the explanatory variables of these regressions suggests that some bias may be present in these equations. Likewise the wholesale margin equations had relatively low multiple correlation coefficients and the current wholesale price was included as an explanatory variable.

**Ex Post Predictions**

At the completion of the study data for two additional quarters, the fourth quarter of 1958 and the first quarter of 1959, were available. The predicted and the observed values of the dependent variables for these two quarters are compared in Table 8. The estimated standard deviation\(^1\) is included in the table to aid the comparison.

The consumer demand equations predicted the retail price well, the differences between the observed and the estimated

\[^1\] The standard deviation is the sum of squared residuals divided by the degrees of freedom and should not be confused with the standard error of estimate. The standard error of estimate is given by the product of the standard deviation and the quantity \(\sqrt{1 + 1/n + \sum \frac{c_{ij}^2}{1} + 2 \sum_{i<j} c_{ij} x_i x_j}\) where the \(c_{ij}\) are the elements of the inverse of the \(XX'\) matrix and the \(x_i\) are deviations of the explanatory variables from their respective means.
Table 8. Estimated and observed values of endogenous variables, 1958-4, 1959-1

<table>
<thead>
<tr>
<th>Prediction equation</th>
<th>Variable</th>
<th>Time period</th>
<th>Observed value</th>
<th>Estimated value</th>
<th>Observed minus estimated</th>
<th>s</th>
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<tr>
<td>V, Table 1</td>
<td>P^R_t</td>
<td>1958-4</td>
<td>50.08</td>
<td>49.91</td>
<td>0.17</td>
<td>1.31</td>
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<td></td>
<td></td>
<td>1959-1</td>
<td>47.51</td>
<td>47.88</td>
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<tr>
<td>VI, Table 1</td>
<td>B^R_t</td>
<td>1958-4</td>
<td>52.35</td>
<td>53.79</td>
<td>-1.44</td>
<td>1.32</td>
</tr>
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<td></td>
<td></td>
<td>1959-1</td>
<td>53.67</td>
<td>54.33</td>
<td>-0.66</td>
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<tr>
<td>I, Table 4</td>
<td>M^R_t</td>
<td>1958-4</td>
<td>13.35</td>
<td>13.63</td>
<td>-0.28</td>
<td>0.64</td>
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<td></td>
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<td>1959-1</td>
<td>13.94</td>
<td>13.03</td>
<td>0.91</td>
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<tr>
<td>III, Table 4</td>
<td>B^R_t</td>
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<td>14.81</td>
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<td>1959-1</td>
<td>15.25</td>
<td>14.23</td>
<td>1.02</td>
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<tr>
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<td>S^t</td>
<td>1958-4</td>
<td>79</td>
<td>-18</td>
<td>97</td>
<td>33</td>
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<td>1959-1</td>
<td>131</td>
<td>51</td>
<td>80</td>
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<td>III, Table 5</td>
<td>S^t</td>
<td>1958-4</td>
<td>51</td>
<td>47</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1959-1</td>
<td>-3</td>
<td>-25</td>
<td>22</td>
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<tr>
<td>IV, Table 6</td>
<td>M^W_t</td>
<td>1958-4</td>
<td>4.66</td>
<td>4.44</td>
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<td>1959-1</td>
<td>4.45</td>
<td>4.74</td>
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<tr>
<td>VIII, Table 6</td>
<td>M^W_t</td>
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<td></td>
<td></td>
<td>1959-1</td>
<td>2.01</td>
<td>1.93</td>
<td>0.08</td>
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</table>

Values falling easily in the range suggested by the deviations from regression.

Changes in beef storage were satisfactorily predicted, but the pork equation underestimated the changes in pork storage by sizeable amounts. Portions of the data contained in the pork equation fell outside the range observed during the sample period. In particular, the difference between the
spring and fall farrowings, $\Delta F$, was far outside the range of the sample. During the period studied the difference ranged from 14.8 to 22.0 million head with a mean of 19.0 million head. In 1958 the difference was 10.0 million head, a deviation from the sample mean almost twice as large as any observed during the sample period. The observations of the table suggest that either the coefficient for $\Delta F$ was overestimated from the sample data or that the coefficient is non-linear.

The retail margins are predicted moderately well for the two quarters although both the beef and pork margins were above levels observed for the respective quarters during the sample period. Combining the fact that the beef equation underestimated the margin by about one dollar for both quarters with the fact that the previous two quarters were also underestimated by lesser amounts suggests that a structural change may have taken place in retail margin behavior.

The pork wholesale margin is predicted well, but the beef wholesale margin for the fourth quarter of 1958 was considerably overestimated. This overestimation may be traced to a large deviation in cow slaughter. During the sample period cow slaughter varied between 46.5 and 35.7 per cent of the fourth quarter slaughter while cows were only 27.1 per cent of the total slaughter of this quarter in 1958. The portion of total beef grading choice was represented in the
estimating equation by the difference between cows as a percent of total slaughter and the percent of steers grading prime or choice at three major markets. The 1958 observation indicates that this variable overestimates the increase in margin flowing from decreases in cow slaughter.

In summary, the consumer demand, the beef storage, pork retail margin and pork wholesale margin equations performed well when used to make *ex post* predictions for the two quarters following the sample period. In two cases, pork storage and beef wholesale margin, explanatory variables fell outside the range observed during the sample period and the predictions were less satisfactory.
SUMMARY AND CONCLUSIONS

Equations were designed and estimated statistically from post-war quarterly data in an attempt to explain the behavior of consumer demand, retail margins, wholesale margins and cold storage stocks for beef and pork. Lags were included in the equations to obtain information on the nature of time reactions at the various levels of the marketing channel.

In general lags were important at all levels of the pork and beef economy except for consumer demand in which case the evidence was inconclusive. The inclusion of the lagged dependent variable significantly improved the predictive ability of most of the equations. Caution is necessary, however, in interpreting the regression coefficients of these variables as structural coefficients since the presence of autocorrelation in the errors may seriously bias the coefficients. Tests for autocorrelation performed upon the residuals generally yielded non-significant test values. Unfortunately these tests are not precise when lagged endogenous variables are included among the explanatory variables and there is reason to believe that the tests are biased toward non-significance.

Only a moderate proportion of the total variation in wholesale and retail margins was explained by the regressions. In the neighborhood of 60 per cent of the variation other than seasonal variation was explained by the regressions and in all cases at least one variable other than the lagged
endogenous variable was significantly different from zero.

Results of the study are summarized by marketing level below:

1. **Consumer demand** - Regression equations employing current price as the dependent variable and including the respective price lagged one period among the explanatory variables yielded an estimate of the short run price elasticity of demand (at the mean) of 0.90 for pork and 0.80 for beef. The corresponding long run elasticities were 0.62 for pork and 0.68 for beef. There was, however, some evidence of positive autocorrelation in the residuals of these equations and if in fact the error term is auto-correlated the elasticities given above are biased. Further the substitution of lagged quantity for lagged price in the estimating equations yielded estimates of the long run elasticity which differed little from the short run elasticity. The elasticity estimates in the latter case were about 0.75 for pork and 0.70 for beef. Thus there is neither clear evidence for accepting nor rejecting the hypothesis of differing elasticities for a quarter relative to longer periods.

An increase of one per cent in the quantity of pork consumed resulted in an estimated decrease in the price of beef of 0.25 per cent at the means. Correspondingly an increase of one per cent in the consumption of beef resulted in a 0.39 per cent decrease in the price of pork at the mean.
Estimates of income elasticities in the neighborhood of one-half were obtained for both beef and pork. The high correlation between time and income resulted in large standard errors for these estimates, however. The results of this study agree with most studies of the demand for beef and pork in that a definite downward trend in the demand for pork and a less pronounced upward trend in the demand for beef is observed. Other things being equal there was an estimated decrease in the retail price of pork of about 30 cents per 100 pounds per quarter. There was an estimated upward trend in the retail price of beef of 14 cents per 100 pounds per quarter.

Significant seasonal variation was observed for both beef and pork demand. Pork demand is lowest during the second and third quarter. Demand during the first quarter is higher by some four to six dollars retail price (per hundred weight). That is, during the first quarter a given quantity will move into consumption at a retail price four to six dollars above the price resulting if the same quantity was consumed during the second quarter. Likewise demand during the fourth quarter exceeds the second and third quarter by seven to ten dollars retail price. The estimated shifts in demand differ depending upon the type of lags included in the equation. During the third and fourth quarters the demand for beef is about four dollars retail price above the first and second quarter level.
2. **Retail margin** - The retail margin equation for pork indicated that for a dollar decrease in the wholesale price of pork the retail margins widened by 16 cents. For beef a decrease of one dollar resulted in an estimated increase in the margin of 50 cents during the third and fourth quarters and a six cent increase during the first and second quarters. An increase in the beef wholesale price resulted in an estimated increase of eight cents in the pork retail margin while an increase in the pork wholesale price resulted in an estimated increase of 15 cents in the beef retail margin.

The coefficient for lagged margin in the pork equation was 0.17 but non-significant. The coefficient seems to indicate that there is a lag only in the response of the retail price of pork to changes in wholesale price. On the other hand the coefficient for lagged margin in the beef equation was 0.33 (standard error 0.11) suggesting a lag in margin adjustment as well as in price adjustment.

Most seasonal effects were non-significant but the results indicated a tendency, other things being equal, for the pork margin to be highest during the third and fourth quarters. The beef margin tended to be higher during the fourth quarter with the level of the margin differing little for the remaining three quarters.

3. **Storage** - The storage equation for pork indicates that about 31 per cent of the quarterly change in farm produc-
tion is absorbed by changes in stocks during the first, third, and fourth quarters and about ten per cent during the second quarter. In the case of beef, stocks absorb approximately nine per cent of the production change for the first, second, and third quarters and about 25 per cent for the fourth quarter. During the period of stock accumulation the difference between spring and fall farrowings exerted a significant effect upon the accumulation of pork.

The construction of an expectational model for stocks introduced as explanatory variables stocks lagged two periods as well as stocks lagged one period. Stocks lagged two periods improved the fit of the equations and hence their predictive ability, but caution is necessary in interpreting the results. The results suggest that the coefficient of physical adjustment in stocks and the coefficient of adjustment for expectations are both near one-half.

The variables described above did not fully account for the seasonality of storage. Pork stocks, in the average, increased some 190 million pounds during the first quarter and decreased 50 million pounds during the third quarter which was not explained by the included variables. Likewise, an accumulation of about 50 million pounds of beef during the fourth quarter was observed which was not explained by the included variables.

4. Wholesale margin - The results indicate that margins
widen as the farm production of the respective commodity increases; the pork margin (per 100 pounds live weight) widened an estimated 90 cents for each billion pounds increase in farm production while the estimated increase in the beef margin was about $1.15 per billion pounds increase in farm production.

A one dollar decrease in the wholesale price of beef (per 100 pounds live weight equivalent) resulted in a nine cent decrease in the beef margin. On the other hand, the coefficient for the change in the wholesale price of pork obtained in the pork margin regression was near zero. Thus the effect of the change in beef production on the beef margin should not be interpreted independent of the effect of the wholesale price change.

The wholesale margin on choice beef (the prices and margins of choice beef were used throughout the study) increased as the proportion of choice beef in farm marketings increased. The respective margin lagged one period entered the beef equation with a coefficient of 0.28 and the pork equation with a coefficient of 0.46, indicating a lag in margin adjustment, particularly in pork.

Other things being equal the beef margin is seasonably highest during the first and fourth quarters and lowest during the second quarter. Similarly pork margins (other things equal) are highest during the third quarter and lowest during
the fourth quarter. Since, however, a large increase in pork marketings occurs during the fourth quarter the observed margins are highest at that time.
SUGGESTIONS FOR FURTHER STUDY

The results of this study indicate that lag models are useful in explaining the behavior of the livestock marketing system and suggest that similar procedures might be applied to other products.

Of the possible approaches available for obtaining additional information on the beef and pork economy it is suggested that the analysis of behavior for periods less than a quarter would be useful. In particular the week appears to be an important planning period for both packers and retailers. Also additional studies attempting to isolate the manner in which packers formulate expectations, and investigating the pricing policies of packers and retailers would prove very useful to those attempting statistical analysis of this sector.

At several points in this study the difficulty in interpreting structurally the least squares estimates obtained from equations of the Koyck-Nerlove type has been mentioned. The difficulty arises from the possible presence of autocorrelation in the error term and the resulting bias in the coefficients, and from the absence of an adequate test for the autocorrelation properties of the errors. This leads to a particularly unfortunate impasse since the presence of differing long and short run elasticities has quite different policy implications than does the presence of autocorrelation
in the errors. This brief discussion emphasizes the importance of further study of the estimation of this type of equation.

The following approach is suggested as a possible method of investigating the estimate of long run elasticity obtained from a Koyck type model. Given that the parameters of the original model

\[ y_t = a \sum_{i=0}^{\infty} \lambda^1 x_{t-1} \]

were estimated by a least squares fit of

\[ y_t = ax_t + \lambda y_{t-1} \]

it is then possible to estimate a second equation such as

\[ y_t = a'x_t + a''z_t \]

where \( z_t = \sum_{i=1}^{n} \lambda^1 x_{t-1} \), \( \hat{\lambda} \) is the estimate of \( \lambda \) obtained from (2) and \( n \) is chosen to give the desired accuracy in \( z_t \). Comparison of the statistics obtained from equation (2) and (3) furnishes information on the influence of autocorrelation on the original estimates and on the validity of the assumptions of (1).
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ACKNOWLEDGEMENTS

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APPENDIX
Table 9a. Major series used in analysis - prices* (not deflated)

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*aSources: (95), (84), (91).

*bWholesale price per 100 pounds of major cuts.

*cWholesale price per 100 pounds liveweight, including by-product allowance.
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<td>21.55</td>
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<td>3166</td>
<td>3422</td>
<td>421</td>
<td>205</td>
<td>19.55</td>
<td>20.59</td>
</tr>
</tbody>
</table>

\[a\] Source: (93).

\[b\] Per capita consumption.
Table 9b. (Continued)

<table>
<thead>
<tr>
<th>Year</th>
<th>Q_P Ft</th>
<th>Q_B Ft</th>
<th>P_s</th>
<th>P_s</th>
<th>Q_P Rt</th>
<th>Q_B Rt</th>
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</thead>
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<tr>
<td>1956-1</td>
<td>2941</td>
<td>3447</td>
<td>514</td>
<td>188</td>
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<td>136</td>
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<td>21.53</td>
</tr>
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<td>166</td>
<td>117</td>
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<td>21.32</td>
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<td>3645</td>
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<td>244</td>
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<td>3507</td>
<td>352</td>
<td>180</td>
<td>15.89</td>
<td>214.6</td>
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<td>3376</td>
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</tr>
<tr>
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<td>2743</td>
<td>3291</td>
<td>206</td>
<td>174</td>
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<td>20.00</td>
</tr>
</tbody>
</table>
Table 9c. Major series used in analysis - miscellaneous

<table>
<thead>
<tr>
<th>Year</th>
<th>Wages in food and liquor stores</th>
<th>Cows + total slaughter</th>
<th>Prime and choice steers + Consumer price index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1949-1</td>
<td>1273 1.23</td>
<td>31.66</td>
<td>59.82</td>
</tr>
<tr>
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<td>1338 1.27</td>
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<tr>
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<td>1330 1.34</td>
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<tr>
<td>1952-1</td>
<td>1352 1.40</td>
<td>30.19</td>
<td>60.79</td>
</tr>
<tr>
<td>1953-1</td>
<td>1419 1.48</td>
<td>28.61</td>
<td>54.17</td>
</tr>
<tr>
<td>1954-1</td>
<td>1400 1.56</td>
<td>32.59</td>
<td>61.33</td>
</tr>
</tbody>
</table>

**Source:** (94).

\[\Delta x_t \] Source: (96).

\[\text{Deflated, per capita.} \]

\[\text{Not deflated.} \]
Table 9c. (Continued)

<table>
<thead>
<tr>
<th>Year</th>
<th>(Y_t)</th>
<th>(\Delta F)</th>
<th>Wages in food and liquor stores</th>
<th>Cows + total slaughter</th>
<th>Prime and choice steers + total steers</th>
<th>Consumer price index</th>
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<td>53.34</td>
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