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An Econometric Analysis of Supply Response for Cattle and Hogs

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Preface

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Highlights

The United States livestock industry has experienced volatile prices due to seasonal and cyclical production levels. Changes in livestock prices usually cause changes in quantities supplied in future production periods. Production changes are not instantaneous because of the reproductive biology of livestock and the length of time required for market animals to reach slaughter weight. Therefore, time is an important restriction on significant changes in output. Livestock breeding herds must be expanded before the number of market animals can be increased. Price increases, then, may cause supplies of market animals and meat to decline in the short run, but to increase in the long run.

The objective of this study was to estimate supply responses for beef and pork in the United States caused by price changes in cattle and hogs. The distributed lag formulation method was used to estimate supply response because of the reproductive biology of livestock.

Beef supply elasticity coefficients for changes in cattle prices were inelastic for both 2nd and 3rd degree polynomial models. Negative signs of the coefficients in the short run indicated that beef supply initially moves in the opposite direction to a cattle price change. The supply response was positive in the long run because increased (decreased) production from increasing (decreasing) breeding herds is felt on the market.

Pork supply elasticity coefficients for changes in hog prices were similar to beef coefficients--inelastic and negative initially but positive in the long run. The impact of a change in corn price was elastic, which indicates that hog producers are responsive to changes in the price of feed.

Reasons for the inelastic supply response from price changes include the time lag in adjusting production to price signals; the fact that many livestock enterprises are small and supplement other farm enterprises, or large with no other alternative uses for resources available; and exogeneous factors such as weather, government programs, supplies of competing meats, etc.

Cattle and hog production and price cycles are expected to continue because of the reproductive biology of livestock. Therefore, livestock producers should be aware of these cycles and make the necessary production and marketing decisons to profit from them.

AN ECONOMETRIC ANALYSIS OF SUPPLY RESPONSE FOR CATTLE AND HOGS

Won W. Koo, Timothy A. Petry, and Craig Anderson*

Introduction

The United States livestock industry has been characterized by volatile prices due to seasonal and cyclical production of cattle and hogs and changes in demand of beef and pork. Seasonal and cyclical production and the resulting price variations are caused by the reproductive biology of livestock and climatic conditions that affect time periods within the year when livestock can best utilize available forages and feed.

Supply response for agricultural products is based on economic and noneconomic factors. Prices of agricultural products play an important role in production decisions. The production decision, however, is constrained by other noneconomic factors such as seasonality, technological innovation, geographic location, importance of specific enterprises, and reproduction period. This is especially true in estimating producers' supply response for livestock.

The knowledge of the nature of supply response is necessary in formulating government agricultural policy including price support programs, stabilization schemes, and programs aimed at diversification. Similarly, such responses are used implicitly in production planning and price forecasts which subsequently become a basis for decisions made by the private sector, particularly by agribusiness firms. In spite of the usefulness of this information, few recent studies have been completed. The purpose of this study was to estimate supply responses for beef and pork in the United States associated with price changes but subject to the biological reproductive process of cattle and hogs.

Most previous studies dealing with supply of livestock were inspired by the pioneering work of Koyck and of Nerlove (1,4). In these studies, the relationship between supply and price was assumed to be such that the response is highest immediately after the change in price, then declines geometrically as the length of the lag time increases. More recently, distributed lag formulation based on a polynomial lag was used to estimate lag effects on supply response (2,3). Geometric lag formulation assumes that the supply response is greatest initially and declines in a linear manner over time. Polynomial lag foumulation is not restricted to any pre-assumed shape and is more flexible than geometric lag models in capturing lag effects of prices. Polynomial lag formulation was selected for this research, but it was necessary to address several statistical problems. The model contains two parameters--length of lag and degree of polynomial--which must be specified in integer terms. The parameters are determined subject to somewhat subjective judgements of the researcher unless they are known on a priori basis.

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United States Cattle and Hog Industry

Cattle

Cattle production in the United States is comprised of animals bred and raised for beef production and animals raised for dairy production. Dairy steers and cull cows are also important sources of beef. Cattle are produced in every state; however, the size and type of operation varies widely due to the many different topographic, climatic, soil, and vegetative situations that exist throughout the U.S. Cow herd sizes range from less than 25-head herds that utilize uncroppable land on small farms to greater than 1,000-head cow herds that utilize private and public grazing land.

Cattle numbers have been increasing since records were first kept in 1867. Inventory numbers reached a record high in 1975 at 132 million head and have declined cyclically to 102 million head in 1987 (Figure 1). While the overall trend is upward, the rate of growth has not been uniform because of cyclical variations that occur. Production of beef per animal has also increased, so the trend in production has actually increased more than have inventory numbers. Factors that have led to increased production include improved breeding, feeding, and management factors; an increasing proportion of slaughter of grain-fed animals; and an increasing proportion of the cattle inventory composed of beef cattle rather than dairy cattle.

The cyclical nature of the cattle industry may be observed in inventory numbers, beef production, and prices. Price cycles tend to be opposite of beef production cycles, but cattle inventory numbers lag price turning points by two to four years. For example, when cattle inventory numbers are declining and prices increasing, at some point prices reach levels which entice producers to increase sizes of cow herds. The retaining of heifers to increase herds, however, further reduces beef production and causes prices to go even higher, so beef production declines and inventories increase. These higher prices encourage producers to add more heifers to herds.

Ironically, when production increases to levels that depress prices, further increases in production are imminent for several years into the future due to production decisions that have already been made. In fact, when prices reach low enough levels to cause producers to decide to reduce cow herd sizes, production increases even further because fewer heifers from an already relatively large calf crop are kept for breeding and more cows are culled, further depressing prices.

The underlying cause of the cattle cycle, then, is the reproductive biology of the species, coupled with producers' decisions to expand or liquidate cow herds as economic forces dictate. The time lag in adjusting production to price, due to the reproductive biology of cattle, takes several years and is illustrated in Figure 2. Cattle reproduce and grow slowly compared to other meat animals, and this is the major factor affecting the length of time involved in producers attempting to adjust production to price. Since the reproductive biology cannot be changed given current technology, cattle cycles will continue to occur.

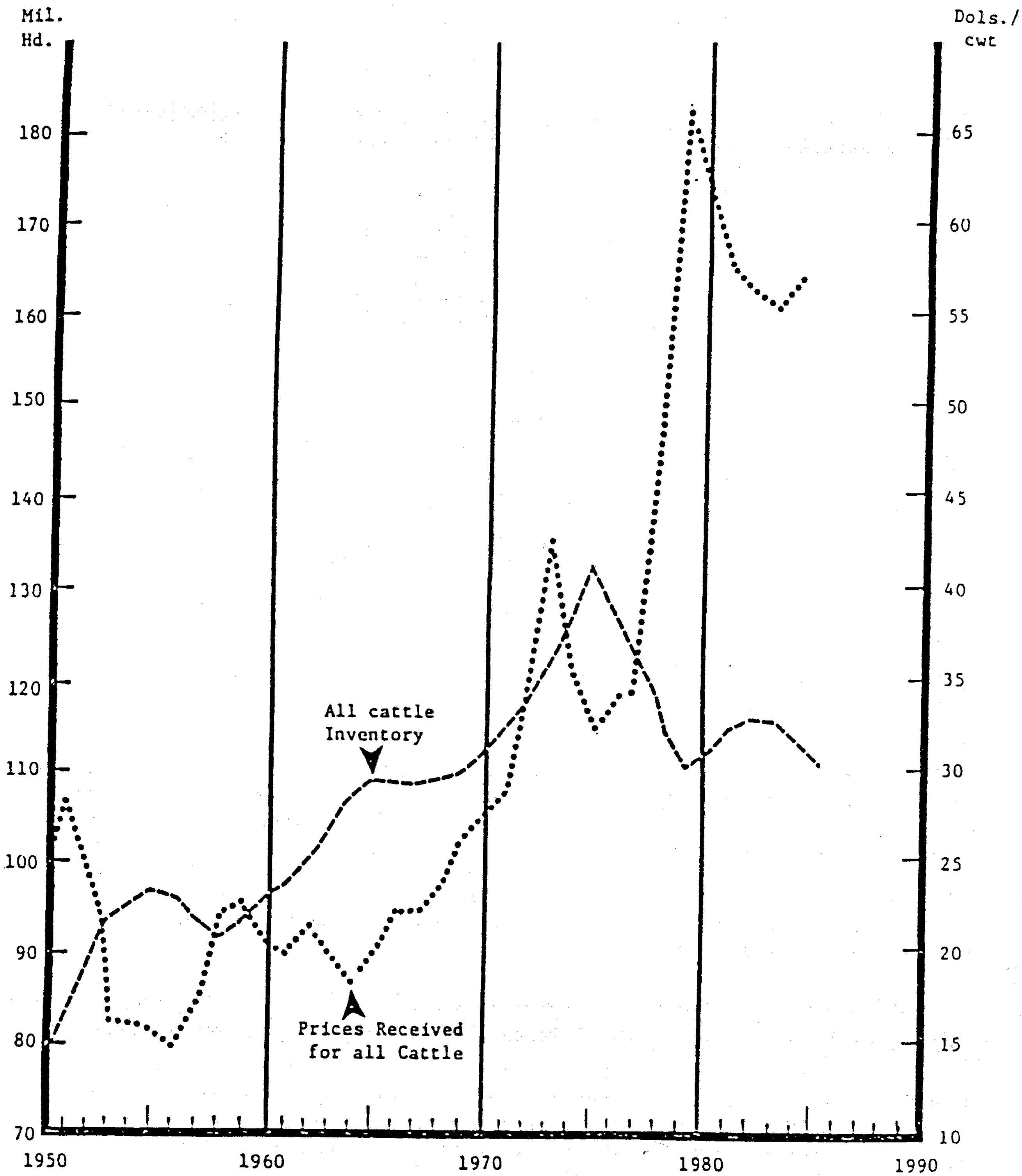

Figure 1. Cattle Inventory and Prices, United States, 1950-1985.

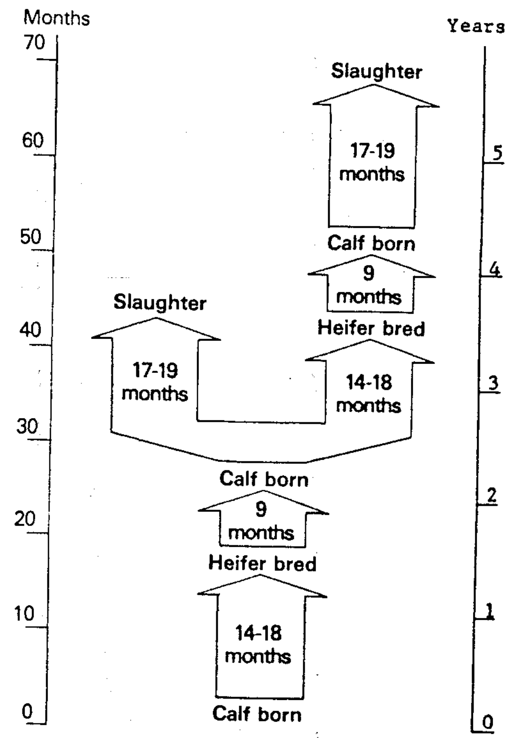

Figure 2. Reproductive Biology of Cattle Affects Supply Response by Producers

If only internal factors--cattle prices and inventories--affect supply response, the degree of adjustment may be minor. This is true because many beef production units are either small and supplement other major sources of income such as growing crops or oilseeds, or are large with no other production alternative available for the grazing land. The economic incentive for these units to produce in any one year exists as long as cash costs are covered. Therefore, prices have to decline quite dramatically to force liquidation of these herds.

When exogenous factors such as costs of production, weather, and changing supplies of competing meats occur during a cycle, sharper inventory adjustments may result. Combinations of external factors, led by widespread drought, contributed to major liquidation in the mid-1950s and caused the record liquidation of cows in the last half of the 1970s. High interest rates in the early 1980s and ample supplies of competing meats, especially poultry, in the mid-1980s are factors which have restricted herd expansion. Cattle inventory numbers in the 1980s were between 102 and 115 million head compared to the 120 to 132 million head inventories in the mid-1970s.

Cattle prices also exhibit seasonal price variations caused by supply and/or demand factors that recur at similar times each year. Cattle prices tend to generally increase during the first half of the calendar year and decrease during the last half. Feeder cattle prices tend to peak in the spring when the demand for feeder cattle is greatest--especially for grazing purposes. Prices for feeder cattle usually reach the low for the year when the peak movement to market occurs--usually November or when winter begins in the cattle producing area. Fed steer and heifer prices usually peak in early summer when production of beef and competing meats is low and bottom in the fall when production of beef and competing meats is high.

Hogs

Hog production in the U.S. includes a wide range of sizes and kinds of production units. Factors such as age of facilities and degree of mechanization of facilities, single or multiple enterprise production units, kinds of feed grown or purchased, and geographic location affect cost of production and supply response. Hog production units range in size from only a few sows to large units selling more than 15,000 head annually. Larger units tend to have high capital/labor ratios, total confinement and highly mechanized facilities.

Hog inventory numbers increased steadily from the mid-30 million head range when records were first kept in 1867 to the mid-60 millions in the 1920s. Since the 1920s the long-term trend has been level at about 55 million head; however, there have been significant cyclical swings above and below the trend. The all time high in hog numbers occurred during World War II at over 80 million head. Hog numbers in early 1987 were about 51 million head. Pork production has increased over time even though numbers have been stable. This increase is due to improved breeding, feeding, and management factors that have allowed heavier muscled hogs to be marketed at younger ages than formerly was the case. Pork production has increased, but per capita consumption of pork has remained stable due to the increasing human population in the United States.

Over the years hog inventories, slaughter, and prices have followed definite cyclical patterns. Hog producers make production decisions before fundamental factors influencing prices for subsequent production are known. The reproductive biology of hogs, although shorter in length than cattle, causes a lag time to exist between the time when prices are reflected to producers from consumers and when production adjustments can be made. The time period involved between breeding a sow and the slaughter of offspring is about 10 months. Since individual hog producers do not know the decisions being made by other producers, over-reactions to good times and bad have resulted in the cyclic pattern of production and prices.

Hog production is influenced by the price of hogs and the availability of feed grains, especially corn. If hog prices are above costs of production and/or there is an ample supply of corn, hog producers generally decide to increase production and vice versa. A theoretical four-year hog production and price cycle is illustrated in Figure 3.

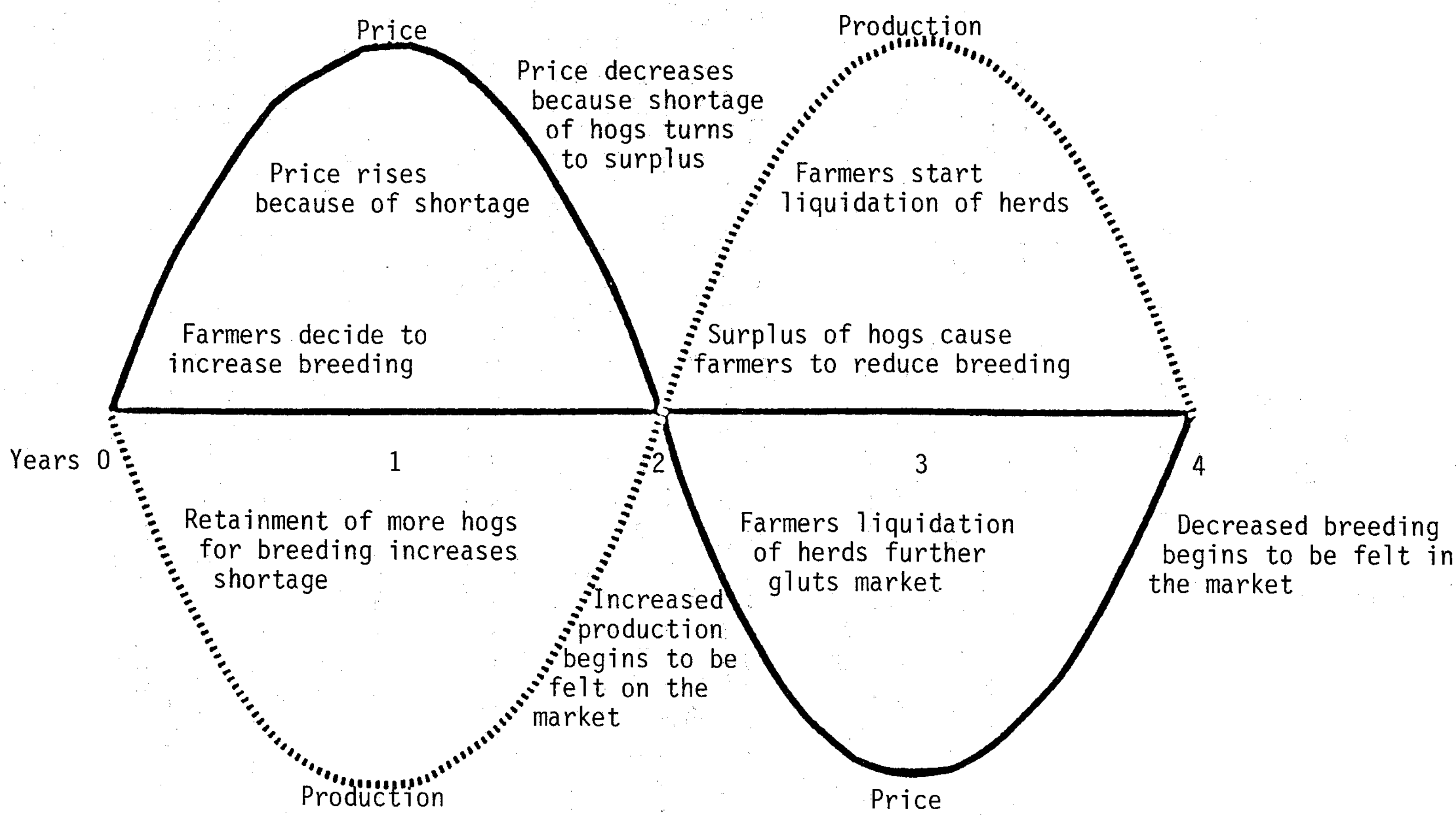

Figure 3. Theoretical Four-Year Hog Cycle

Theoretically hog (pork) production and price cycles should move in opposite directions. The pattern is quite evident in Figure 4, although some irregularity may exist. The hog numbers (inventory) cycle lags the price cycle by about one year. For example, numbers usually peak about one year after prices peak due to the reproductive biology of the animal.

Seasonal production and price patterns are also quite evident in the hog industry. Hog prices are directly related to marketings of hogs; which in turn, are related to time of farrowing, weather conditions, and feeding programs.

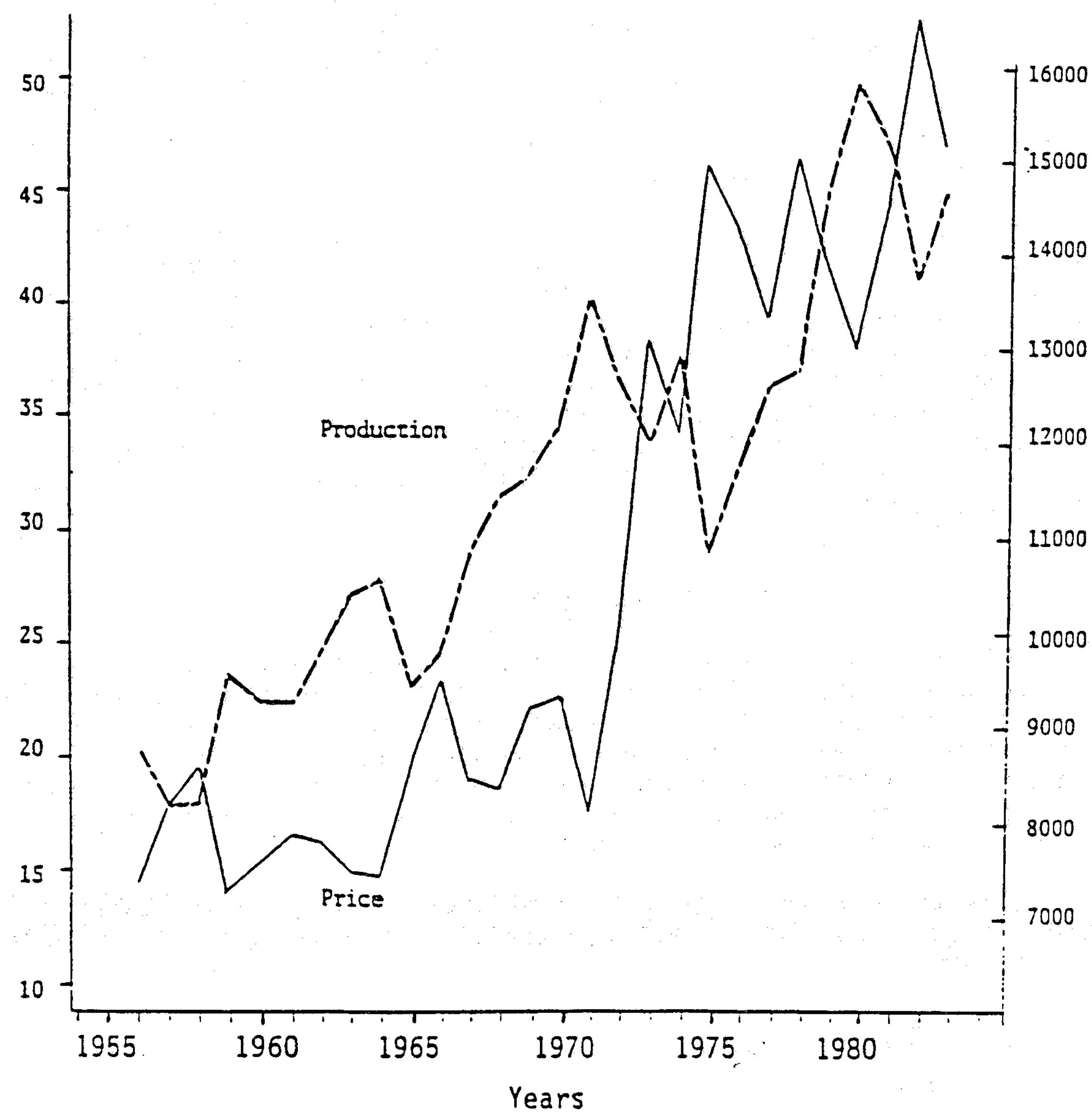

Figure 4. Hog Price and Production Cycles, United States, 1956-1983.

The marketing year pig crop is categorized by four quarters: 1) winter--December, January, February; 2) spring--March, April, May; 3) summer--June, July, August and 4) fall--September, October, and November. Generally, it takes five to six months from birth to produce a slaughter-weight hog. Farrowings and pig survival are both reduced during the winter quarter due to colder weather and during the hotter summer quarter. The largest pig crop of the year is produced during the relatively mild-weather spring quarter, while the smallest pig crop is produced during the extreme cold of the winter quarter.

While demand factors will affect actual price levels, the price pattern for slaughter hogs is established primarily by supply factors. The price pattern that emerges from the climate-controlled production pattern shows: 1) highest prices during the summer quarter, when the winter pig crop (smallest of the marketing year) comes to market; 2) relatively strong prices during the winter quarter, as the summer heat-reduced pig crop is marketed; 3) a low point during the spring as pigs born during the milder weather of fall are marketed and 4) another low point during the fall, as the relatively large spring pig crop comes to market.

It has been hypothesized that with larger production units farrowing and marketing hogs on a continuous, year-around basis, the seasonal production and price variation would be less pronounced. However, greater seasonal variations in hog prices were evident during 1979 through 1983 than during 1956 through 1960 (Figure 5). Evidently, there are still many hog producers who continue to schedule farrowings in either or both the spring or fall. Because of the seasonality in sows farrowing and the six-month feeding period, high slaughter levels and low prices usually occur in the spring (April) and fall (November) and low production and high prices typically occur in the summer (July and August).

Development of Model

This section focuses on development of the econometric models used to estimate supply responses for beef and pork. The estimated models and their implications are presented in the subsequent section. These sections may not be understood by livestock producers. However, they are included as a documentation for other researchers to follow in possible subsequent research. A final section subtitled "Implications for Livestock Producers" can be used to interpret the results of the econometric modeling.

A firm in a competitive market produces a bundle of products to maximize its profit. Assume that the firm's total revenue and cost functions are as follows:

$$TR_j = \sum_{i=1}^{n} P_i Q_i \qquad (1)$$

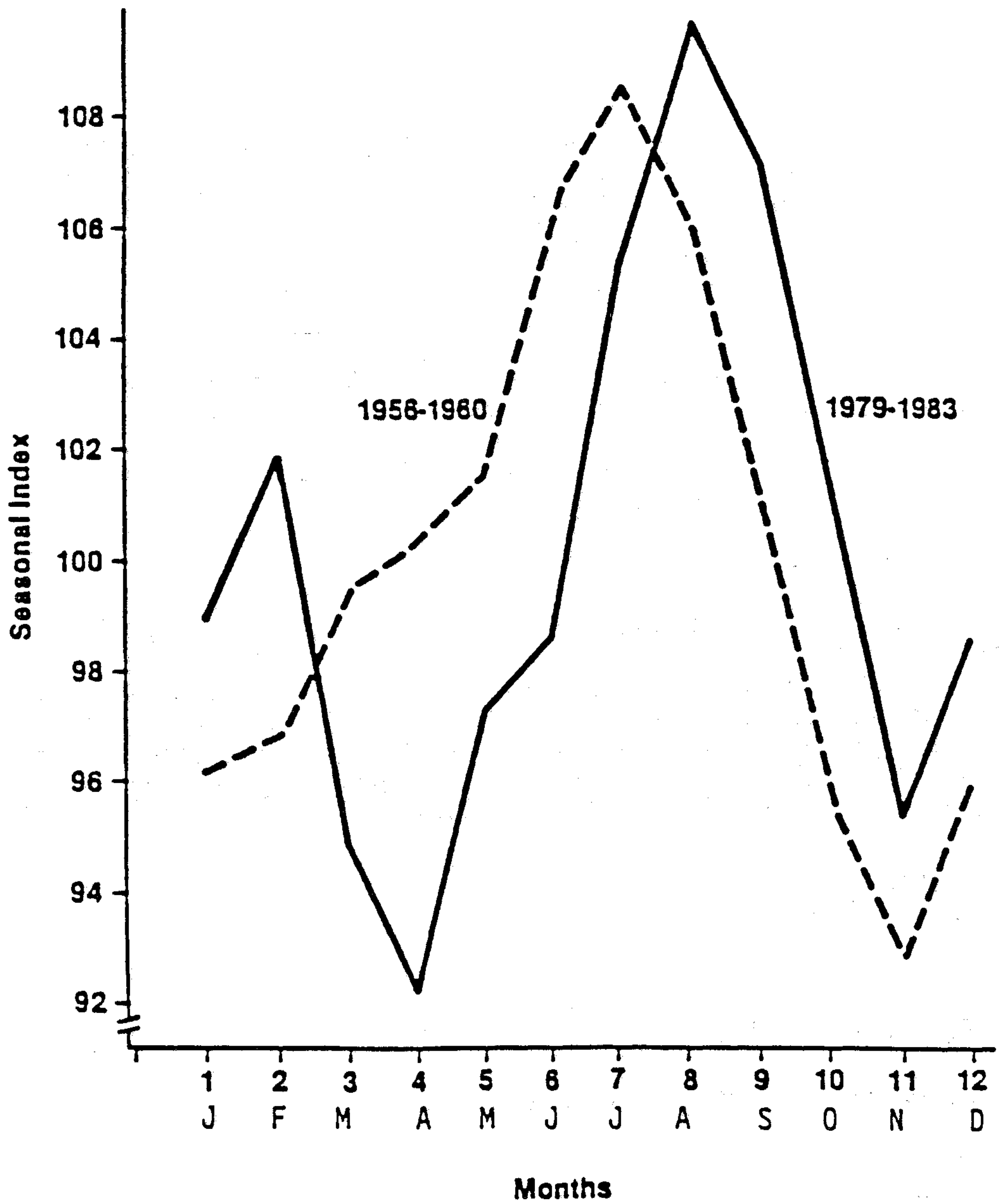

Figure 5. Seasonal Index of Hog Prices, United States, 1956-1960 and 1979-1983.

$$TC_j = f(Q_1, Q_2 \ldots Q_n) \tag{2}$$

where

TR is total revenue of the j^{th} firm
P_i is price of i^{th} commodity produced in the j^{th} firm
Q_i is the quantity of i^{th} commodity produced in the j^{th} firm
TC_j is total cost of producing products $Q_1, Q_2 \ldots Q_n$

Then the firm's net profit function can be obtained as follows:

$$\pi_j = \sum_{i=1}^{n} P_i Q_i - f(Q_1, Q_2 \ldots Q_n) \tag{3}$$

The optimal quantities of individual products that the firm must produce to maximize its profits can be obtained from the first order condition of Equation 3. The first partial derivatives with respect to Q_i is

$$\frac{\partial \pi_j}{\partial Q_i} = P_i - f_i(Q_1, Q_2, \ldots Q_n) \qquad (i=1, 2, \ldots n) \tag{4}$$

where f_i is the first order partial derivative of the cost function with respect to Q_i (marginal cost), and other variables defined previously.

The first order condition can be derived by setting the first order derivatives equal to zero as follows:

$$P_i = f_i(Q_1, Q_2 \ldots Q_n) \qquad (i=1, 2, \ldots n) \tag{5}$$

This indicates that the market price of the i^{th} product must equal its marginal cost. The first order condition is shown in Figure 6. For the given market price P_1, the firm must produce Q_1 units of the commodity as shown in Figure 6. The market supply function can be derived by aggregating all individual firm's production at the given price P_1. The individual firm's supply of the i^{th} product can be mathematically derived by solving the first order conditions for Q_1, Q_2 ... and Q_n as follows:

$$\begin{aligned}
Q_1 &= f_1(P_1, P_2 \ldots P_n) \\
Q_2 &= f_2(P_1, P2 \ldots P_n) \\
&\vdots \\
Q_n &= f_n(P_1, P2 \ldots P_n)
\end{aligned}$$

The market supply function of i^{th} product is

$$\overset{*}{Q_i} = \sum_{j=1}^{m} Q_{ji} \tag{6}$$

where

$\overset{*}{Q_i}$ is the market supply of the i^{th} product
Q_{ij} is the j^{th} individual's supply schedule of the i^{th} product.

This implies that market supply of i^{th} product is a function of the price of the product and prices of its competing products. The second order condition for the firm which maximizes profit can be obtained from the Hessian

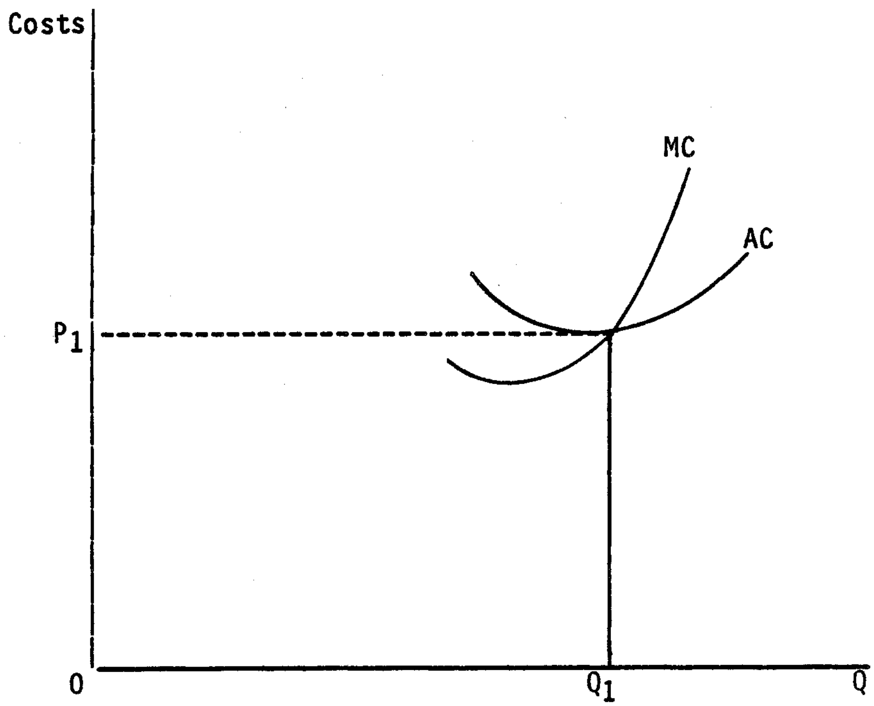

Figure 6. Theoretical Average and Marginal Cost Curves for a Firm.

determinant. The second derivatives of Equation 3 form the Hessian determinant as follows:

$$|H| = \begin{vmatrix} f_{11} & f_{12} & f_{13} & \cdots & f_{1n} \\ f_{21} & f_{22} & f_{23} & \cdots & f_{2n} \\ \vdots & \vdots & \vdots & & \vdots \\ f_{n1} & f_{n2} & f_{n3} & \cdots & f_{nn} \end{vmatrix}$$

where

$|H|$ is the Hessian determinant and f_{ij} is the second order partial with respect to individual commodities i and j.

The second order conditions are:

$|H_1|<0, \ |H_2|>0, \ |H_3|<0 \ \ldots \ (-1)^n|H_n|>0$

Supply Model of Livestock

Supply response of livestock is different from that of other agricultural products. The biological length of the reproduction period of cattle and hogs is greater than one year; about four years for cattle and two years for hogs (Figures 2 and 3). This implies that changes in the price of cattle, for example, have a minimal impact on beef supply in the same time period. In fact, changes in the price of cattle in time t will affect the supply of beef in time t + 4 more than in any other time. This indicates that supply models of livestock contain dynamic aspects through the reproduction process.

There are limited numbers of livestock supply response studies in the literature possibly due to the complex nature of the production and decision making process. Most beef and pork supply response models used a finite distributed lag structure. Kulshreshtha (2) estimated cattle supply response for Western Canada using a polynomial lag formulation. The polynomial lag structure was specified for two variables: cattle price and feed grain price with a different lag structure for each. Models for feed and pork in this study were developed on the basis of Kulshreshtha's approach. Kulshreshtha's supply response study for cattle used 3rd degree polynomial with 18 quarters lag on price of cattle and 2nd degree polynomial with 8 quarters lag on feed grain price. Since the full length of the cattle cycle is considered to be 8 to 10 years, it might be more appropriate to consider the entire cycle rather than one-half of the entire cycle used by Kulshreshtha. The conceptual model developed for this study is similar to the Kulshreshtha study except for the number of lags used on the price variable. Also regarding uncertainty related to lag effects of price on beef supply, both 2nd and 3rd degree polynomials on cattle price were used. The lagged model used for supply response for beef is written as

$$Q_t = \alpha_0 + \sum_{i=1}^{K} \beta_i P_{t-i} + \sum_{j=1}^{J} \gamma_j pf_{t-j} + \alpha_1 P^c_{t-m}$$

$$+ \alpha_2 S_{1t} + \alpha_3 S_{2t} + \alpha_t S_{3t} + e_t \tag{7}$$

where

Q_t = total beef supply during time t
P_{t-i} = price of cattle at time t-i
Pf_{t-j} = price of feed grain at time t-j
P^c_{t-m} = price of competing commodities at time t-m
S_{1t} = dummy variable representing quarter 1 in time t
S_{2t} = dummy variable representing quarter 2 in time t
S_{3t} = dummy variable representing quarter 3 in time t

The lag effects of cattle price on beef supply can be described in both quadratic (β_{2i}) and cubic (β_{3i}) terms as follows:

$$\beta_{2i} = \lambda_0 + \lambda_1 i + \lambda_2 i^2 \tag{8}$$

and

$$\beta_{3i} = \lambda_0 + \lambda_1 i + \lambda_2 i^2 + \lambda_3 i^3 \tag{9}$$

Similarly, the lag effects of feed grain price on supply of beef can be described as:

$$\gamma_j = \delta_o + \delta_1 i + \delta_2 i^2 \tag{10}$$

combining Equations 7, 8, and 10 yields:

$$Q_t = \alpha_o + \lambda_o \sum_{i=o}^{K} P_{t-i} + \lambda_1 \sum_{i=o}^{K} i \cdot P_{t-1} + \lambda_2 \sum_{i=o}^{K} i^2 \cdot P_{t-i} + \delta_o \sum_{i=o}^{J} Pf_{t-j} \tag{11}$$

$$+ \delta_1 \sum_{j=o}^{J} j \cdot Pf_{t-j} + \delta_2 \sum_{j=o}^{J} j^2 \cdot Pf_{t-j} + \alpha_1 P^c_{t-m} + \alpha_2 S_{1t} + \alpha_3 S_{2t} + \alpha_4 S_{3t} + e_t$$

This equation can be rewritten as

$$Q_t = \alpha_o + \lambda_o Z_{ot} + \lambda_1 Z_{1t} + \lambda_2 Z_{2t} + \delta_o W_{ot} + \delta_1 W_{1t} + \delta_2 W_{2t} + \alpha_1 P^c_{t-m} \tag{12}$$

$$+ \alpha_2 S_{1t} + \alpha_2 S_{2t} + \alpha_3 S_{3t} + e_t$$

where

Z_{ot}, Z_{1t}, Z_{2t}, W_{ot}, W_{1t}, and W_{2t} are the transformed price variables.

The variables can be transformed as follows:

$$Z_{ot} = \sum_{i=o}^{K} P_{t-i} = P_t + P_{t-1} + P_{t-2} + \ldots + P_{t-K} \tag{12-a}$$

$$Z_{1t} = \sum_{i=o}^{K} i \cdot P_{t-i} = P_{t-1} + (2)P_{t-2} + \ldots + (K)P_{t-K} \tag{12-b}$$

$$Z_{2t} = \sum_{i=1}^{K} i^2 \cdot P_{t-i} = P_{t-1} + (4)P_{t-2} + \ldots + (K^2)P_{t-K} \tag{12-c}$$

$$W_{ot} = \sum_{j=1}^{J} Pf_{t-j} = Pf_t + Pf_{t-1} + \ldots Pf_{t-J} \tag{12-d}$$

$$W_{1t} = \sum_{j=1}^{J} \sigma \cdot Pf_{t-j} = Pf_{t-1} + (2)Pf_{t-2} + \ldots (J)Pf_{t-J} \tag{12-e}$$

$$W_{2t} = \sum_{j=1}^{J} j^2 Pf_{t-j} = Pf_{t-1} + (4)Pf_{t-2} + \ldots (J^2)Pf_{t-j} \tag{12-f}$$

Similarly, combining Equations 7, 9, and 10 yields:

$$Q_t = \alpha_o + \lambda_o Z_{ot} + \lambda_1 Z_{1t} + \lambda_2 Z_{2t} + \lambda_3 Z_{3t} + \delta_o W_{ot} + \delta_1 W_{1t} + \delta_2 W_{2t} \quad (13)$$

$$+ \alpha_1 P^c_{t-m} + \alpha_2 S_{1t} + \alpha_2 S_{2t} + \alpha_3 S_{3t} + e_t$$

where

$$Z_{3t} = \sum_{i=1}^{K} i^3 \cdot P_{t-1} = P_{t-1} + (8)P_{t-2} + \ldots (K^3)P_{t-3} \quad (13\text{-a})$$

and other variables as previously defined.

Under the assumption that the disturbance terms in Equations 12 and 13 are independent, identically distributed normal variate with a mean of zero and a constant variance [$e_t \sim iiN(o, \sigma^2)$], parameters in these Equations 12 and 13 can be estimated by using the ordinary least squares (OLS) estimate.

The biological length of hog production is greater than one year and the full length of the hog cycle is about four years. Meilke, Zwart, and Martin (3) estimated supply response for hogs by using 2nd order polynomial formulation on hog price with 10 quarters lag. They did not introduce polynomial lag formulation on feed grain price because adjustments in production of hogs are quicker than in cattle. The model used for this study is similar to that by Meilke, Zwart, and Martin. The only difference is the model used in this study uses both 2nd and 3rd degree polynomial with 17 quarters' lag while the study by Meilke used one-half cycle (10 quarters). The model based on a finite distributed lag model is specified as

$$Q_t = \alpha_o + \sum_{i=1}^{K} \beta_i P_{t-i} + \alpha_1 fP_{t-1} + \alpha_2 P^c_{t-m} + \alpha_3 S_{1t} + \alpha_4 S_{2t} \quad (14)$$

$$+ \alpha_5 S_{3t} + e_t$$

where

Q_t = quantity of pork in time t
P_{t-i} = price of hogs at time t-i
fP_{t-1} = price of feed grain at time t-1
P^c_{t-m} = price of competing commodities
S_{1t} = dummy variable representing quarter 1 in time t
S_{2t} = dummy variable representing quarter 2 in time t
S_{3t} = dummy variable representing quarter 3 in time t

The lag effects of hog price on pork supply response are the same as Equations 8 and 9. Combining Equations 14 and 8 yields the 2nd degree polynomial model as follows:

$$Q_t = \alpha_o + \lambda_o \sum_{i=1}^{K} P_{t-i} + \lambda_1 \sum_{i=1}^{K} i \cdot P_{t-i} + \lambda_2 \sum_{i=1}^{K} i^2 \cdot P_{t-i} + \alpha_1 fP_{t-1} \tag{15}$$

$$+ \alpha_2 P^c_{t-m} + \alpha_3 S_{1t} + \alpha_4 S_{2t} + \alpha_5 S_{3t} + e_t$$

This Equation can be rewritten as:

$$Q_t = \alpha_o + \lambda_o Z_{ot} + \lambda_1 Z_{1t} + \lambda_2 Z_{2t} + \alpha_1 fP_{t-1} + \alpha_2 P^c_{t-m} + \alpha_3 S_{1t} \tag{16}$$

$$+ \alpha_4 S_{2t} + \alpha_5 S_{3t} + e_t$$

Similarly, combining Equation 14 and 9 yields the 3rd degree polynomial model as follows:

$$Q_t = \alpha_o + \lambda_o \sum_{i=1}^{I} P_{t-1} + \lambda_1 \sum_{i=1}^{K} i \cdot P_{t-1} + \lambda_2 \sum_{i=1}^{K} i^2 P_{t-i} + \lambda_3 \sum_{i=1}^{K} i^3 P_{t-1} \tag{17}$$

$$+ \alpha_1 fP_{t-1} + \alpha_2 P^c_{t-m} + \alpha_3 S_{1t} + \alpha_4 S_{2t} + \alpha_5 S_{3t} + e_t \ldots$$

This equation can be rewritten as:

$$Q_t = \alpha_o + \lambda_o Z_{ot} + \lambda_1 Z_{1t} + \lambda_2 Z_{2t} + \lambda_3 Z_{3t} + \alpha_1 fP_{t-1} + \alpha_2 P^c_{t-m} \tag{18}$$

$$+ \alpha_3 S_{1t} + \alpha_4 S_{2t} + \alpha_5 S_{3t} + e_t$$

where Z_{ot}, Z_{1t}, Z_{2t}, and Z_{3t} are the transformed price variable. The transformation procedure on the price data is the same as those in Equations 12-a, 12-b, 12-c, and 13-a. Like Equations 12 and 13, parameters in Equations 16 and 18 can be estimated by using OLS estimation under the assumption that e_t is an independent and identically distributed normal variate with zero mean and constant variance [$e_t \sim$ iin $(0, \sigma^2)$].

The estimation of distributed lag model requires choice of the maximum lag period. For a pre-selected degree of polynomial, varying lengths of lags were specified. The choice is based on the R^2, and t-values of the estimated parameters. Since in the beef supply model the prices of both cattle and feed grains are introduced as lagged variables, the choice of the length of lag is further complicated. Now the concern associated with the beef model is not with the choice of lengths of lag for one variable with a preselected degree of polynomial, but with the lengths of lag for two variables. The following scanning procedure is used:

1. Select alternative lag periods for cattle price with the pre-selected lag period of feed grain price, and choose one lag period based on R^2 and consistency of the sign.

2. Select alternative lag periods for price of feed grain with the selected lag period for price of cattle and choose one based on the same criterion used in step 1.

For the pork model, step 1 is used with corn price lagged one period.

Data were based on quarterly statistics for the first quarter of 1960 through the last quarter of 1984. Data were obtained from Livestock and Meat Statistics (USDA), Agricultural Prices (USDA), and Livestock and Poultry Situation Reports (USDA).

Rationale for Estimation of Statistical Models

In the preliminary estimates, Durbin-Watson statistics indicated that error terms in the beef and pork models were serially correlated over the time series. The model was re-estimated using Cochrane-Orcutt's iterative procedure.

Two models based on Equations 12 and 13 were estimated for beef supply response (Table 1). One is based on 2nd degree polynomial on cattle price with lag period 32 quarters and 2nd degree polynomial on the price of feed grain (C) with a lag period of 8 quarters. The price of competing products (P_{t-m}) was not included in the model mainly because production of livestock is highly specialized and consequently is not easily substitutable when considering supply. Additional variables included in the empirical supply response model for beef are the number of cattle on feed and the number of breeding stock. The second model was the same as the first one except the fact that the polynomial lag on cattle price was of degree 3 rather than degree 2.

Two supply response models for pork similar to Equation 11 were also estimated (Table 1). One is based on 2nd degree polynomial on the price of hogs with a lag period of 8 quarters. The pork model also includes the price of corn lagged by four quarters (CP_{t-4}). The second model was the same as the first one except the fact that polynomial lag on the second model was of degree 3 on hog price.

Seasonal dummy variables for quarters 1, 2, and 3 were included for all beef and pork models. The estimated models have high R^2s ranging from 0.87 to 0.93. The estimated parameters have t-values higher than 2.0 except the polynomial terms associated with the price of feed grains in the beef model. This indicates that most variables are statistically significant at the 5 percent significance level. The t-values associated with seasonal dummy variables also indicated that supply responses for beef and pork are seasonal although their biological production period is greater than one year. Seasonality is due to weather conditions in major livestock producing regions, and large numbers of livestock and poultry slaughtered in the fall, but few slaughtered in midsummer.

Supply Response for Beef

The estimated coefficients for beef model 1 are similar to those for beef model 2, indicating that there are no differences in estimating supply of beef between 2nd and 3rd degree polynomials. It is generally known that the 3rd degree polynomial is more flexible than the 2nd degree polynomial. The

TABLE 1. ESTIMATED POLYNOMIAL LAG FUNCTIONS FOR BEEF AND PORK SUPPLY IN THE UNITED STATES, 1964-1984

	Beef		Pork	
	Beef Model 1	Beef Model 2	Pork Model 1	Pork Model 2
Intercept	4,317	4,087	5,465	5,338
Z_0 (λ_0)	-5,261 (6.93)[a]	-5,287 (7.26)	-5,912 (3.77)	-11,575 (8.06)
Z_1 (λ_1)	545 (3.70)	560 (3.69)	1,476 (4.19)	5,374 (8.32)
Z_2 (λ_2)	-12.08 (2.69)	-11.53 (2.64)	-74.7 (3.59)	-651 (7.35)
Z_3 (λ_3)	-- --	0.04 (0.52)	-- --	23.3 (6.60)
W_0 (δ_0)	97,655 (2.02)	89,686 (1.79)	-- --	-- --
W_1 (δ_1)	-45,168 (1.72)	-42.357 (1.61)	-- --	-- --
W_2 (δ_3)	4,420 (1.41)	4,126 (1.31)	-- --	-- --
Cattle on feed	0.15 (3.18)	0.15 (3.10)	-- --	-- --
Cow inventory	0.038 (1.16)	0.039 (1.19)	-- --	-- --
Corn price	-- --	-- --	-82,717 (1.90)	-84,358 (2.40)
S_1	-394 (3.98)	-401 (3.98)	-141 (4.42)	160.1 (6.22)
S_2	-326 (5.12)	-339 (5.04)	-182 (5.00)	-205.6 (7.00)
S_3	-21.8 (0.50)	-31.4 (0.65)	-352 (10.9)	-355 (13.71)
R^2	0.87	0.86	0.90	0.93
DW	1.98	1.97	1.52	1.97

[a]Numbers in parentheses indicate t-values for the corresponding variables.

maximum price effects on the supply response of beef can be calculated from Equations 8 and 9. The estimated Equations 8 and 9 are

$$\beta_{2i} = -5{,}261 - 545i - 12.08i^2 \tag{19}$$

$$\beta_{3i} = -5{,}287 - 560i = 11.53i^2 + 0.04i^3 \tag{20}$$

Taking derivations of Equations 19 and 20 with respect to i gives

$$\frac{\partial \beta_{2i}}{\partial i} = 545 - 24.16i \tag{21}$$

$$\frac{\partial \beta_{3i}}{\partial i} = 560 - 23.06i + 0.12i^2 \tag{22}$$

Setting these first derivatives equal to zero and solving for i gives the value of i which maximizes price effects. The value of i is equal to 22 in the 2nd degree polynomial and is equal to 20 in the 3rd degree polynomials. This implies that the entire length of the cattle cycle is approximately 44 quarters or 11 years based on the 2nd degree polynomials and is approximately 40 quarters or 10 years based on the 3rd degree polynomial. The price effects can also be seen in Figure 7. The current cattle price has the minimum effect on supply of beef in the same time period. The price effect increase in t+1, t+2 ..., reaches the maximum in t+20 or t+22, and then starts to decline. The lagged supply response on changes in price is due mainly to the biological reproductive process of cattle.

Estimated supply elasticities with respect to cattle price and price of feed grain are shown in Table 2. Supply elasticities with respect to cattle price are negative in the first two or three years, and then turn positive. In the entire period of the cycle, the short-run beef supply elasticities with respect to cattle prices are very inelastic. They ranged from 0.001 in the 10th year to 0.049 in the 6th year in beef model 1 and from 0.001 in the 10th year and 0.051 in the 6th year in beef model 2. The long-run supply elasticity with respect to cattle price is 0.109 in beef model 1 (the 2nd degree polynomial) and is 0.116 in beef model 2 (3rd degree polynomial).

The price effects of feed grain on the supply of beef over time can be calculated from the polynomial portion of the estimated model. The estimated models (Equation 9) for 2nd and 3rd degree polynomials are

$$\beta_i = 97{,}655 - 45{,}168i + 4{,}420i^2$$

and

$$\beta_i = 89{,}686 - 42{,}357i + 4{,}126i^2$$

These equations are convex from the origin of two dimensional graphs. The price effect (value of β) is maximum when $i = 5.1$ in both equations. This implies that feed grain price changes affect the supply of beef for 2.5 years. Beef supply elasticities with respect to price of feed grain were 0.193 in the first year and -0.258 in the second year. These elasticities also reflect

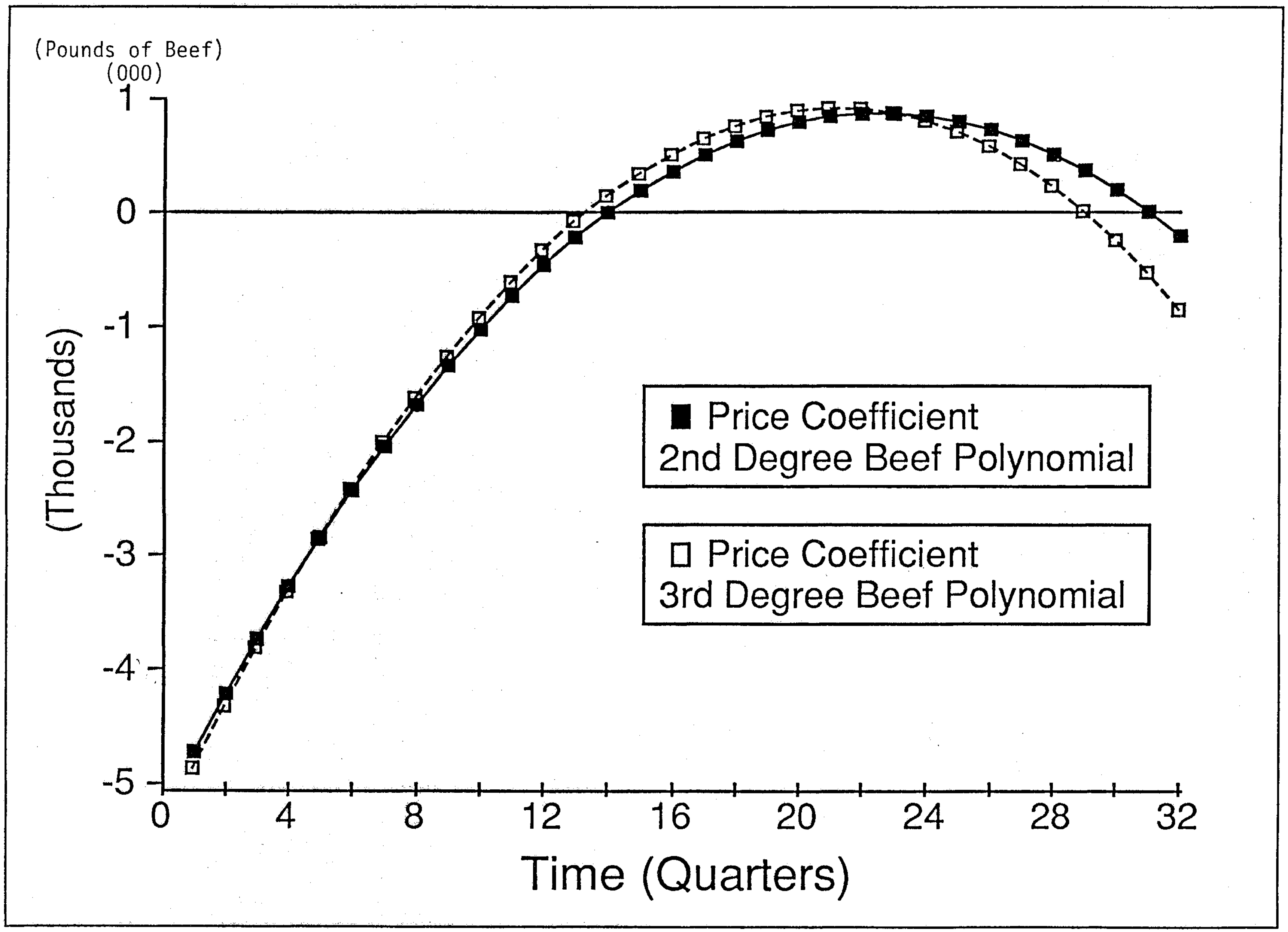

Figure 7. Effects of Lagged Prices on Supply of Beef in Time t, United States, 1964-1984

TABLE 2. ESTIMATED BEEF SUPPLY ELASTICITIES WITH RESPECT TO CATTLE PRICES AND PRICE OF FEED GRAIN, UNITED STATES, 1964-1984

Year	Cattle Price		Price of Feed Grain	
	2nd Degree	3rd Degree	2nd Degree	3rd Degree
1	-0.170	-0.157	0.193	0.164
2	-0.102	-0.086	-0.258	-0.27
3	0.049	-0.033	--	--
4	0.005	0.009	--	--
5	0.028	0.039	--	--
6	0.049	0.051	--	--
7	0.034	0.022	--	--
8	0.009	0.015	--	--
9	0.002	0.003	--	--
10	0.001	0.001	--	--
Long-run	0.109	0.116	-0.065	-0.106

lagged effects of price of feed grain on supply of beef. Supply elasticities obtained from the 3rd degree polynomial model are similar to those for the 2nd degree polynomial model. Long-run supply elasticities are also very inelastic with price of feed grain in the 2nd and 3rd degree polynomial models. The negative sign on price of feed grain indicates that supply of beef tends to decline as price of feed grain increases.

The total number of cattle on feed and the number of breeding animals have a positive relationship with the quantity of beef supplied in cattle models 1 and 2. The number of cattle on feed is statistically significant at the 5 percent level, while the number of breeding animals is not significant in both models. This is mainly because the number of breeding animals is to some extent correlated with the price of cattle.

Supply Response for Pork

The maximum price effects on supply response of pork can be calculated from the estimated coefficients of Equation 9. The estimated 2nd and 3rd degree polynomial equations are:

$$\beta_i = -5{,}912 + 1{,}476i - 74.7i^2 \tag{23}$$

and

$$\beta_i = -11{,}575 + 5{,}374L - 651i^2 + 23.3i^3 \tag{24}$$

Taking the derivative of these equations with respect to i, setting these derivatives equal to zero, and solving for i yields the value of i which maximizes price effects (β_i). The price effect is maximum when i is equal to 10 in Equation 16 and when i is equal to 6 in Equation 17. This implies that the entire length of the hog cycle is approximately 20 quarters or five years based on the 2nd degree polynomial and is 12 quarters or three years based on 3rd degree polynomials. Actual hog cycles do vary in length from three to six years so both models may be appropriate in explaining supply response. The price effects over time are shown in Figure 8. Based on the t-values and R^2s associated with each model, the 3rd degree polynomial model more adequately explains price effects than the 2nd degree polynomial model. The supply model with the 3rd degree polynomial has higher t-values and R^2s than that based on the 2nd degree polynomials.

Supply elasticities are all inelastic over the four-year period. They start with negative sign and turn positive. The elasticity is maximum in the 3rd year in the 2nd degree polynomial model and is maximum in the 2nd year in the 3rd degree polynomial model, which indicates the most response occurs at those times.

Unlike supply elasticities with respect to price of hogs, price of corn is elastic in the 2nd and 3rd degree polynomial models. This indicates that the price of corn is highly correlated to supply of pork.

Implications For Livestock Producers

The estimated beef and pork supply elasticity coefficients generated by the models and documented in Tables 2 and 3 have important implications for producers. Elasticity is a term used by economists to measure the responsiveness caused by a certain action. Supply elasticity coefficients measure the amount of change in quantity of beef or pork supplied caused by a change in cattle or hog prices. If the percentage change in quantity supplied is greater than the percentage change in price, the relative responsiveness is defined as elastic and means that producers are responsive to changes in price. However, if the percentage change in quantity supplied is less than the percentage change in price, the relative responsiveness is defined as inelastic and means that producers are less responsive to changes in price.

The beef supply elasticity coefficients for changes in cattle prices were inelastic for both the 2nd degree and 3rd degree polynomial models (Table 2). The negative signs of the coefficients for years 1 and 2 for the

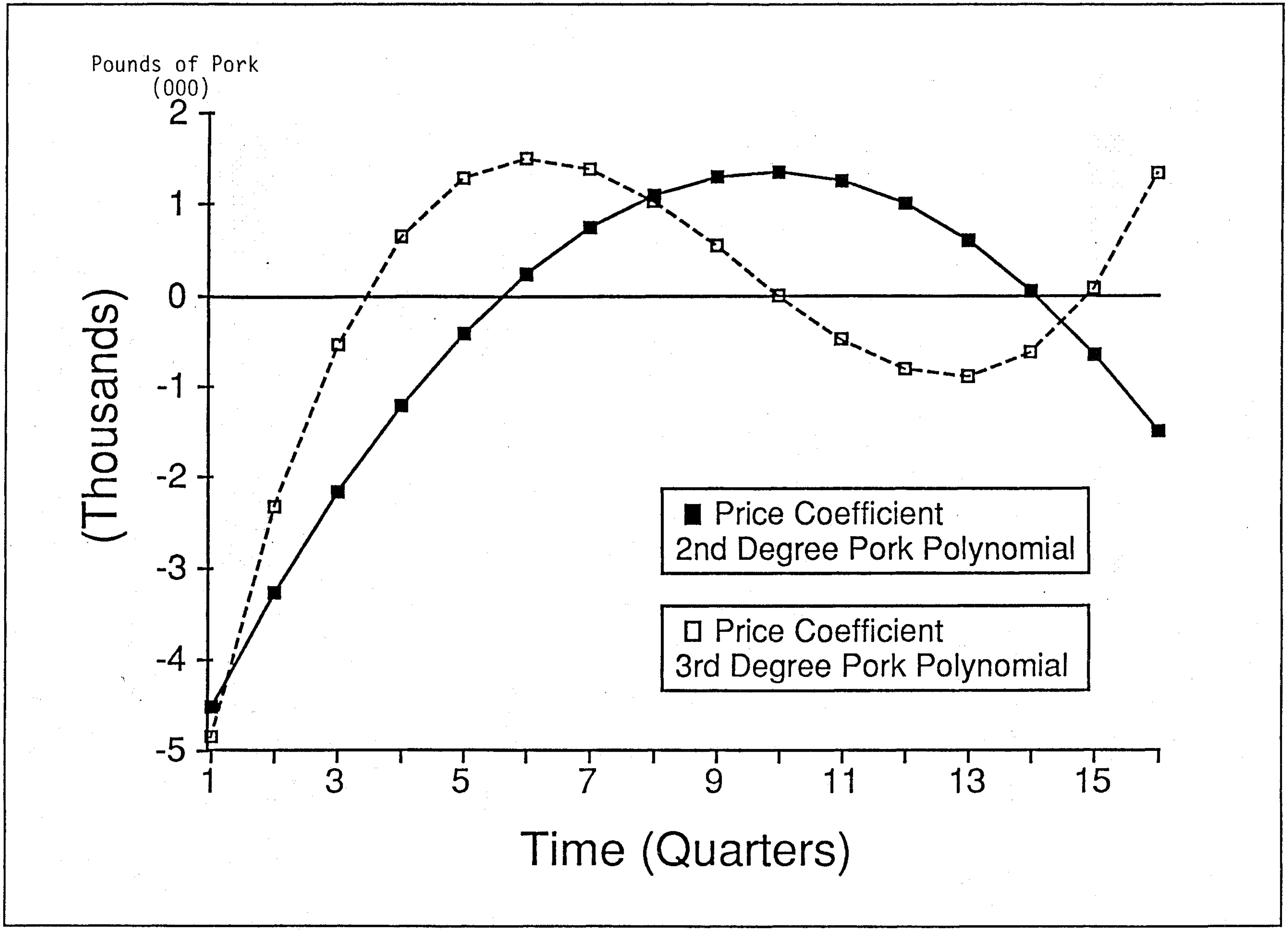

Figure 8. Effects of Lagged Prices on Supply of Pork in Time t, United States, 1964-1984

TABLE 3. ESTIMATED PORK SUPPLY ELASTICITIES WITH RESPECT TO HOG PRICE AND PRICE OF CORN, UNITED STATES, 1964-1984

Year	Hog Price		Corn Price	
	2nd Degree	3rd Degree	2nd Degree	3rd Degree
1	-0.206	-0.270	-1.44	-1.47
2	-0.008	0.092	--	--
3	0.079	0.046	--	--
4	0.012	0.011	--	--
Long-run	0.109	0.149	--	--

2nd degree polynomial and years 1, 2, and 3 for the 3rd degree polynomial indicate that beef supply actually moves in the opposite direction to a cattle price change during the first years of the cycle, i.e., price increases cause supply declines and price declines cause supply increases. The reason that there is negative response initially is because when prices are high, producers keep heifers to increase breeding herds instead of selling them for fattening and slaughter. This retention actually causes lower beef supplies. Conversely, when prices reach low points, producers decide to reduce herd sizes and sell a higher percentage of the increased supply of heifers as well as cull cows, which further increases slaughter and beef supply.

However, by year 3 for the 2nd degree polynomial and/or year 4 for the 3rd degree polynomial the supply response is positive because the increased (decreased) production from increasing (decreasing) breeding herds is felt on the market.

The interpretation of the coefficients may be made in the following manner (using the 2nd degree polynomial as an example). A 1 percent change in cattle price will cause a -0.170 percent change in beef supply in year 1, a -0.102 percent change in year 2, a 0.049 change in year 3, etc. The long-run coefficient of 0.109 indicates that there is a positive response in beef supplies to a change in cattle price, but the response is inelastic (not great).

The supply of beef is also related to prices of feed grain (corn) although the coefficients are also inelastic. A 1 percent change in the price of feed grain caused a -0.065 change in beef supply in the long run. The old adage that "cheap feed causes cheap livestock" may be partially explained here in that a decrease in the price of feed grain would cause an increase in beef supplies and lower cattle prices, assuming other factors affecting cattle prices remained unchanged.

The reason why cattle supply response was found to be inelastic is because beef supply is related to sizes of previous calf crops and numbers of cattle on feed. Since many calf production units are either small and supplement other major sources of income such as growing crops or oilseeds, or are large with no other alternative available for grazing land, the economic incentive to produce in any one year for these units exists as long as cash costs are covered. Furthermore, once the carrying capacity of land is reached, climatic conditions usually restrict increasing cow herds. Therefore, prices have to change significantly to force changes in herd sizes.

Pork supply elasticity coefficients for changes in hog prices were similar to beef coefficients--inelastic and negative initially but then turning positive (Table 3). The inelastic coefficients indicate that the percentage change in pork supply is less than a percentage change in hog prices. The negative response initially occurs because producers keep gilts to increase herd sizes when prices are high instead of sending them to market, which actually decreases pork supplies. Conversely, when prices fall below cost of production, producers decide to reduce herds and sell gilts and producing sows, which further increases pork supply. However, in subsequent years the supply response is positive because the increased (decreased) production from increasing (decreasing) breeding herds is felt on the market. The long-run coefficients (0.109 and 0.149) indicate that there is a positive response in pork supplies to hog prices (higher hog prices lead to increased pork supply and vice versa) but the response is relatively minimal.

The impact of a change in corn price on the supply of pork was elastic. A 1 percent change in corn prices caused a -1.44 percent change in pork suppply for the 2nd degree polynomial and -1.47 perent change for the 3rd degree polynomial. The negative sign indicates that a decrease (increase) in the price of corn will cause an increase (decrease) in pork supply the next year. A possible reason for hog producers being quite responsive to changes in feed grain prices is that many corn belt farmers have facilities for raising hogs. Some producers have relatively low fixed cost facilities which can go unused and not have a significant impact on profitability of the farm firm. Therefore, when corn prices are high, producers may decide to sell the grain, and when prices are low, the producers may decide to feed the corn to hogs in an attempt to increase its value.

In summary, the econometric models demonstrated relatively small responses in supplies of beef and pork to changes in prices of cattle and hogs. High prices do cause small increases in supplies in the long run and low prices cause small decreases in supplies. Reasons for the inelastic response include the lag time in adjusting production to price signals caused by the reproductive biology of livestock. The fact that many livestock enterprises are small and supplement other farm enterprises, or are large with no other alternative uses available, and that exogenous factors such as weather, government programs, supplies of competing meats, etc., may have a significant impact on supply response. Cattle price cycles tend to be opposite of beef production cycles, but cattle inventory numbers lag price turning points by two to four years. Similarly, pork production cycles are generally opposite of price cycles, but hog inventory numbers lag price cycles by about one year.

Cattle and hog production and price cycles are expected to continue because of the reproductive biology of livestock. Therefore, livestock producers should be aware of these cycles and make the necessary production and marketing decisions to profit from them.

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