CARD Livestock Model Documentation: Pork

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The U.S. hog industry has experienced dramatic structural change as the trend continues for fewer producers with increased enterprise size. Through intensive production practices, efficient use of inputs, and improved disease control measures, large producers have attained more production per sow, more production per unit housing, and lower feed costs (Van Arsdall and Nelson 1984). Pork production has also become less seasonal with the adoption of capital-intensive confinement units. Thus, pork production has become increasingly dominated by enterprises that produce hogs on a year-round basis in a confined environment.

More of the total hog production has become concentrated in large, capital-intensive operations. In 1967 farms with greater than 10,000-head annual sales accounted for less than 8 percent of total number of hogs and pigs sold (U.S. Bureau of the Census 1967). Less than 20 years later, in 1982, they accounted for nearly 50 percent of total number of hogs and pigs sold (U.S. Bureau of the Census 1984). Nevertheless, there are constancies in the U.S. pork industry. Pork production remains regionally concentrated. Nearly 70 percent of the U.S. pork production is in the Corn Belt states.[1] Modest growth has been evident in the South, particularly in North Carolina. Production continues to be dominated by farrow-to-finish operations, with producers retaining control over the entire production phase from breeding to birth to slaughter.

While the hog industry has undergone a dramatic transformation, the biological nature of hog growth processes has remained essentially unchanged. Even though pigs per litter, feed efficiency, and the time of weaning have changed, the hog growth process reflects fixed biological constraints.

This report presents a quarterly econometric model of the U.S. pork sector, which recognizes the constancies within the sector while allowing for technological change. The econometric model is an abstraction of a complex system that aids in comprehensively synthesizing data and causal relationships. With the behavioral relationships formalized, econometric models can be used for analyzing changes in policy, technology, structure, and forecasting.

The model can provide information on likely implications of agricultural and trade policy shifts. Impacts of a technological adoption such as porcine somatotropins can be readily quantified. Evidence of structural change can be examined. The pork industry model provides a means of assessing these and other changes that confront the livestock sector in general, and the pork industry specifically.

The pork model is one of four econometric models developed at the Center for Agricultural and Rural Development (CARD), Iowa State University, for the major components of the livestock sector. The other livestock models include quarterly beef, chicken, and turkey models, which are described in more detail in CARD Technical Reports 2 and 3 (Grundmeier et al. 1989 and Jensen et al. 1989).

The pork model is a self-contained model and can be linked to other subsector models of the livestock and feed grain economy. These linkages are depicted in Figure 1. The pork sector model is linked to the other livestock models through retail meat prices. This linkage assumes that cross-commodity effects originate on the demand side and are a result of consumers' adjustments to changes in relative retail prices. This structure ignores the cross-commodity linkages at the farm level. Sufficiently induced producers could shift from pork production to other enterprises. However, given the concentration of production and the capital-intensive production methods used throughout the pork sector, the farm-level, cross-commodity effect is not included.

The livestock models are also linked to annual feed grain models through the prices of corn and soymeal. The feedback to the annual feed crop models is through grain-consuming animal units (GCAU), high-protein animal units (HPAU), and an index of livestock prices (LPI). These indices give a weighted measure of feed use and provide a compact method of transferring livestock production and price information to the feed grain and soybean complex. The parsimonious set of exogenous economic factors that influence the livestock sector are the interest rate, income through food expenditures, inflation rate, and meat packers' marketing costs.

The econometric model of the pork sector provides a complete depiction of the phases in the pork production process and of the primary demand categories. The supply component of the model tracks producers' breeding herd expansion and contraction decisions. Technical relationships govern the pig crop and subsequent slaughter. The supply component of the model relies upon the regularities in the growth processes of hogs, as well as on the economic behavior of pork producers.

The demand component recognizes that in the short term pork production is essentially fixed, and thus price determination is at the retail level. The demand component also admits consumer adjustments to changes in relative prices and income. Habit formation and imperfect information flows are among the reasons for the partial adjustment process. Consumers' inability to adjust fully implies that the precepts of static consumer behavior dc not hold in the short run. However, in the demand structure the restrictions on consumer behavior are imposed in the long run, which in turn restricts short-run consumer behavior.

The format of this paper is as follows. In the next section an overview of the model is presented. Next, the modeling approach used is contrasted with previous econometric models of the pork economy. The fourth section contains background on the specification of the model and the estimation results. In the fifth section model behavior is compared with previous studies and validated with simulation statistics.

Model Overview

The U.S. quarterly pork model includes representations of the key behavioral relationships within the industry. This section includes a brief overview of the structure and specification of the supply and demand components. The specification of each equation is further detailed in the estimated results section.

The sequential phases in the pork production process provide benchmark information for specifying the supply structure. The supply structure recognizes that current supply is conditioned on past breeding decisions. The size of the breeding herd determines the industry's production capacity, and the stages in production fall sequentially from determination of the breeding herd. This stock-flow relationship in the supply structure of the model is depicted in Figure 2.

The level of supply is primarily determined by breeding herd investment decisions of producers. Producers expand their breeding herds by retaining gilts from slaughter. This investment decision is represented by an equation that reflects additions to the breeding herd. Producers can also adjust their culling rate of sows. The level of sow slaughter reflects producer culling decisions. During expansion sows may be kept in the breeding herd even if they have reduced productivity. Disinvestment by producers requires a liquidation of the breeding herd or a higher rate of sow slaughter. The net difference between additions and sow slaughter defines the change in the breeding herd.

The level of the breeding herd determines the level of the pig crop. The pig crop is either finished and slaughtered or retained for breeding purposes. Thus, the pig crop plays a dual role in the production process: as an intermediate step in the finishing process and as the source for replenishing the breeding stock. The slaughter categories are the next phase in the production process. The pig crop determines subsequent barrow and gilt slaughter; sow slaughter, in part, is determined by the stock of available sows for slaughter.

The slaughter categories, multiplied by their respective live weights, determine total domestic pork production. The slaughter weights adjust to market conditions. Domestic pork production is transformed to a carcass weight equivalent by the equation for total commercial pork supply. Domestic disappearance is defined as the difference between total commercial supply and changes in other use categories. These categories include imports and exports, cold-storage stocks, military use, and on-farm production. Cold-storage stocks are represented by a behavioral equation. The other use categories are treated as exogenous in the model.

As with most other livestock models, the lag structure in the supply block is governed by the biological timetable in the sequential phases of the production process. However, the biological production sequence provides more information than just defining the lag length of explanatory variables in the supply components. Known biological relationships inherent in the pork production process are incorporated in the behavioral equations. These restrictions impose constraints on supply response. Thus, the supply response is governed by the time lags in breeding, gestation, birth, finishing, and slaughter. Of course, supply response is also dependent on producer production decisions. A parsimonious set of input and output prices is included in the supply equation to reflect the variables conditioning producers' behavior. Seasonality is accounted for with quarterly dummy variables.

The method for incorporating biological restrictions in the supply structure was first developed by Johnson and MacAulay (1982) in a quarterly beef model. Historical biological relationships were used to obtain restrictions on the parameter estimates in the supply structure. Thus, biological restrictions imposed by nature can be used as a priori information in the estimation of the stock-flow relationships governing production. This approach has been used subsequently for beef (Okyere 1982; Okyere and Johnson 1987), poultry (Chavas and Johnson 1982), and pork (Blanton 1983; Oleson 1987). In the CARD pork model biological restrictions are imposed in the equations that represent the pig crop and barrow and gilt slaughter.

The biological restrictions can also be imposed in the functional form. Chavas and Klemme (1986) follow this approach in their analysis of investment behavior in the U.S. dairy industry. Similar functional forms are used in the equations that represent additions to the breeding herd and sow slaughter. With this method the biological constraints remain intact, but producers are allowed more behavioral discretion than with constraints imposed through the direct parameter restrictions that characterized early applications of the method.

The demand structure provides a representation of consumer behavior and presumes that consumers cannot instantaneously adjust to shifts in relative prices and income. This persistence in consumption patterns implies the axioms of consumer behavior may be violated in the short run. Thus, consumers may not behave as the static theory would suggest because of habit formation and imperfect information flows. However, in the long run these impediments are presumed not to exist, and thus the restrictions from the consumer theory are imposed on the long-run demand; in turn, they affect short-run demand response.

Price is determined at the retail level. Supply is essentially perfectly inelastic in the current period, and thus the level of the current price is dependent on demand. The price determination process of the pork model is illustrated in Figure 3. The retail price is dependent on domestic pork supply, prices of competing meat, and food expenditures. The retail price is linked to the farm price through an estimated margin. The margin changes in accordance with both demand and supply shifts and with changes in the marketing cost structure for meat packers.

Review of Previous Econometric Models

Econometric models of livestock have advanced slowly in method. Most specifications still have relatively simple supply structures that use distributed lags of input and output prices, time lags, and partial adjustments to production stimuli. Seasonality, an important feature of the livestock industry, is handled with dummy variables. The use of this basic supply structure in part reflects the regularity in the livestock production growth process, ease of implementation and estimation, and the relative success in capturing producer behavior. Demand specifications are predominantly simple linear structures that do not presuppose adherence to the theory of consumer behavior.

Identifying the underlying reasons for the cyclical nature of pork production and prices provided the initial impetus for modeling the pork economy. The cyclical nature of pork production was initially explained as self-generating using the so-called Cobweb theorem (Coase and Fowler 1937; Dean and Heady 1958; Harlow 1960). Early econometric analyses (Foote 1953; Maki 1962) of the livestock-feed economy attempted to quantify the cyclical price-production relationships. These analyses identified the biological sequences inherent in the livestock production processes as one of the underlying factors generating the cycles.

The biological time sequence in the pork production process remains the benchmark for specifying subsequent econometric models of the pork economy. This was reflected in the recursive supply structure advanced by Harlow (1962) that continues to be replicated in later econometric models. The supply of pork is governed by the level of sows farrowing, which is dependent on past hog and feed prices. Farrowing determines hog slaughter, which in turn determines pork production. In this general supply structure a single inventory relation is specified as a partial adjustment relation, which in turn governs subsequent slaughter. Modern examples of analyses using this structure include Freebairn and Rausser (1975) and Stillman (1985).

Often the supply structure first used by Harlow is augmented by intermediate steps between the farrowing and subsequent slaughter with equations that represent the pig crop, the levels of market hogs on feed, and additions to the breeding herd. The structures of these intermediate steps are tied to the biological timetable for pork production, and they include forms of distributed lags in input and output prices. Examples of extended supply structures include Maki et al. (1962), Arzac and

Wilkinson (1979), Brandt et al. (1985), Holt and Johnson (1986), and Skold and Holt (1988).

The economic variables in the inventory specifications also have been extended beyond input and output prices. Measures of relative profitability in competing enterprises, usually beef production, have been included to reflect the opportunity cost in production. MacAulay (1978) included a beef-feeding margin, and Harlow (1962), Freebairn and Rausser (1975), Arzac and Wilkinson (1979), among others, included producer prices of cattle in their hog supply equations.

In many livestock models the demand equations are estimated in price-dependent form with per capita meat quantities and income as the explanatory variables (e.g., Harlow 1962; Heien 1975, 1977). Fox (1953) suggested this specification, since short-term livestock production is essentially fixed. Thus, estimation can proceed with ordinary least squares (OLS). The price-dependent demand form has not always been followed (Freebairn and Rausser 1975; Arzac and Wilkinson 1979). Nevertheless, in general the theory of consumer behavior has not been applied in models of the agricultural sector. The standard forms of demand specifications used in the livestock sector remain static and ad hoc in nature, and linear in the variables (Tomek and Robinson 1977).

Estimation Results

The U.S. quarterly pork industry model contains ten behavioral equations and eight identities. These expressions provide behavioral representations of the major components of the industry supply and demand structure. The supply structure provides a disaggregated characterization of the phases in the production process. The supply block includes behavioral relationships for additions to the breeding herd, sow slaughter, the pig crop, and barrow and gilt slaughter. Breeding herd inventory is derived through an identity. Domestic pork production is derived from the sum of the two slaughter categories multiplied by their respective slaughter weights.

Slaughter weights adjust to movements in input and output prices. Total commercial production in carcass weight follows by direct transformation from farm-level domestic pork production. The demand component consists of retail demand and cold-storage stock equations. The retail price is derived from the retail demand equation. A margin equation defines the retail-farm price spread. Farm production, trade flows, shipments, and military use are exogenous.

The sample includes 80 quarterly observations for the period 1967-1986. Single-equation estimation procedures were used in the supply block and in the retail-farm margin and cold-storage stock equations. Estimation methods employed were nonlinear least squares (NLS), restricted least squares (RLS), and generalized least squares (GLS). Retail demand was estimated within a system containing equations for beef, pork, and chicken per capita consumption. The estimation procedure used in the demand block was iterated seemingly unrelated regression (ITSUR). This procedure provides estimates that asymptotically approach maximum likelihood estimates (Gallant 1987).

The results presented in this section are accompanied by a description of the specification of each equation. The description of results and the underlying specification begins with the supply block. The estimated supply components are presented in Table 1. The quarterly means of the biological ratios, used as prior information in the supply block, are presented in Table 2. The estimates of the demand block and price determination components are presented in Table 3. Definitions of the variables, including details on the data sources and the construction of the variables, appear in Table 4.

Supply Component

The production capacity in the pork industry is dictated by the size of the breeding herd. The breeding herd stock reflects past investment decisions made by producers. Producers can expand the breeding herd and thus increase future production capacity by retaining gilts from the slaughter process. Gilts, which are unbred female pigs, are available for breeding at seven to eight months of age. Since in the short term the number of gilts available for replacement purposes is limited, production must decline in aggregate before the results of additional gilt retention reverberate through to increase production. This dual role of gilts in the pork production process has direct implications on the cyclical nature of production.

In Table 1, the method of estimation follows in parentheses after the title of the supply component. The stock of gilts available for breeding constrains producer investment behavior. This is reflected in the specification of the equation that determines additions to the breeding herd (1). The pig crop, lagged two quarters, appears in the numerator of the logistic function. Pig crop lagged two quarters is multiplied by 0.5, which reflects gilts available for retention in the breeding herd. The two-quarter lag approximates the age at which gilts enter the breeding herd. This places an upper bound on gilt retention that is in the spirit of the biological restrictions developed by Johnson and MacAulay (1982) and applied by others. The functional form that provides the biological restriction is similar in form to the one used by Chavas and Klemme (1986) in their analysis of investment in the dairy industry.

Expansion of the breeding herd is also influenced by variables that do not involve the restrictions imposed by nature in the hog growth process. Since the equation represents an investment decision, additions are also a function of producer profitability expectations for future hog production. Profitability expectations are confined to a simplistic set of input and output prices. With the logistic functional form, incrementally larger increases in output prices and decreases in input prices are required to increase the rate of retention. Thus, the functional form requires increasingly higher profit incentives to induce producers to increase the rate of expansion of their breeding herds.

Included in the set of conditioning variables are the barrow and gilt price, FPPK, divided by the feed cost index, PKFC. These ratios, lagged one and two quarters, represent one component of the profitability expectation. Corn and soymeal prices are included in the feed cost index and are weighted to reflect a typical ration. Feed costs remain the major variable cost in farrow-to-finish operations (Van Arsdall and Nelson 1984; USDA 1986). The lagged structure on these output-input price ratios reflects the approximate time frame of the gilt retention decision.

The real interest rate, RIFCL, is also included as a measure of the cost of credit, since additions to the breeding herd represent an investment. Interest expenses are significant and fixed for farrow-to-finish operations. Also, the logarithm of the time trend is included to reflect increased efficiency in breeding herd stock. The breeding stock has become more productive with reduced weaning ages and with the adoption of better herd management practices. Quarterly dummy variables capture the seasonality in the process.

The signs of the estimated coefficients are as anticipated. The estimates imply that increases in hog prices lead to an expansion of gilt retention. Increases in the producer cost structure reduce retentions, which in turn reduce future pork production. The sign of the logarithm of the time trend is also as expected. The turnaround time for sows in the breeding process decreased over the sample period. Thus, over the sample period fewer additions were required to increase production by the same proportion.

The other determinant of the breeding herd is the outflow of breeding herd stock. This is represented by <u>sow slaughter</u> (2). The biological restrictions are introduced in the sow slaughter equation with the same logistic functional form. The numerator of the logistic functional form is the breeding herd, lagged one quarter. The breeding herd is lagged one quarter because the majority of sows are slaughtered after farrowing and weaning. Weaning usually occurs three to five weeks after birth, and hence the one-quarter lag is a crude approximation.

The level of sow slaughter is also dependent on the same set of input and output prices reflected in the additions to the breeding herd equation (1). However, the lag structure is shifted ahead by one quarter. This means contemporaneous changes in input and output prices can affect sow slaughter and subsequently the level of pork production. The logarithm of the time trend captures productivity increases over the sample period. Again, quarterly dummy variables reflect the seasonal variation of sow slaughter.

As expected, the coefficients in the sow slaughter equation are opposite in sign compared to those for additions to the breeding herd. The results imply that increases in barrow and gilt prices reduce the rate of sow slaughter. Increases in feed costs or the interest rate increase the rate of sow slaughter. Thus, as output prices increase or as costs decline, producers hold sows in the breeding herd for a longer period.

The additions to the breeding herd and the level of sow slaughter are inflows and outflows, respectively, for the breeding herd. The identity that determines the <u>breeding herd inventory</u> (3) represents this stock-flow relationship. The relationship between stocks and flows is based on the identity (Blanton 1983)

$$CI_t + S_t = CI_{t-1} + IN_t,$$

where CI_t is the closing inventory, S_t is the outflow or slaughter, and IN_t is the inflow from one stage to another. The beginning inventory is

CI_{t-1}. By rearranging the identity it is clear that the change in the inventory is equal to the difference between inflows and outflows. This same identity applies to the breeding herd inventory relation. The breeding herd stock is determined by the carry-in inventory, and by the inflows (additions) and the outflows (slaughter)

$$BHUS_t + SSUS_t = BHUS_{t-1} + ABHUS_t.$$

With simple manipulation this stock-flow relationship obtains the identity that determines the breeding herd inventory.

The pig crop (4) and the level of barrow and gilt slaughter (5) are specified as technical relationships and incorporate the biological restrictions first advanced by Johnson and MacAulay (1982). Blanton (1983) incorporated these biological stock-flow relationships in a U.S. quarterly pork model. The specification and estimation of pig crop and barrow and gilt slaughter equations duplicate these specifications.

The biological restrictions use the regularity in the production process as a priori information. The size of the breeding herd essentially determines the size of the pig crop. The number of pigs saved per litter is affected by death loss and the age composition of the breeding herd, as well as advances in production technology. However, in the short term death loss, the age composition of the breeding herd, and existing technology are not readily affected by the prevailing economic conditions. Thus, the level of hog production is assumed entirely based upon the prevailing breeding herd size and breeding decisions. Omitting technological advances, this implies a constant relationship between the prevailing size of the breeding herd and the pig crop.

The level of barrow and gilt slaughter is limited by the number of pigs grown to slaughter weight. Producers can sell market hogs at heavier or lighter weights, but, nevertheless, barrow and gilt slaughter is limited by the previous pig crop. Given regularities in feeding practices, this would imply a constant relationship between the pig crop lagged two quarters and barrow and gilt slaughter. The two-quarter lag of the pig crop represents the five- to six-month time period required to finish a 40- to 45-pound pig to a slaughter weight of 230 to 250 pounds. These two relationships can be summarized with the ratios of the current pig crop to the size of the existing breeding herd, $PCUS_t/BHUS_t$, and the ratio of current barrow and gilt slaughter to the pig crop lagged two quarters, $BGSUS_t/PCUS_{t-2}$. These ratios can be used as prior information in the supply components. The quarterly means and standard deviations for the two ratios are presented in Table 2.

The first ratio suggests that the total breeding herd produces 2.3 to 3.1 pigs per head. This is less than the average pigs per litter saved because it does not account for the number of sows farrowing. On average, 32-42 percent of the breeding herd farrows per quarter. Thus, if the level of farrowing was accounted for, the first ratio implies that an average of 7-7.5 pigs are saved per litter. This corresponds to historical averages. The second ratio of means indicates that 78-94 percent of the hogs at slaughter weights are marketed.

As expected, the quarterly means for the ratios vary by quarters, even though the seasonality of hog production has diminished. Plots of the above ratios against time, by quarter, indicate that changes have occurred. Increased sow productivity and litter size, better feeding practices, reduced death loss, and reduced seasonality are a few of the factors that have led to changes in the ratios over time. To more accurately reflect these changes in seasonality and changes through time, the ratios were detrended by quarter.

The trends in the biological ratios were incorporated by regressing a zero-one dummy variable and the logarithm of the time trend on the biological ratios, by quarter. The plots of the ratios, by quarter, provided indications of threshold points for shifts in the ratios. The general form of the regression was

$$R_i = a_i + b_i * LT * DV_i + c_i * DV_i + e_i,$$

where R_i is the biological ratio; i = 1, 2, 3, 4 denotes the quarter; LT is the logarithm of the time trend; DV_i is one if the year is greater than the threshold point and zero if otherwise; a,b,c are parameters to be estimated; and e_i is the disturbance term. In this framework, a_i yields an unbiased estimate of the quarterly mean if no trend is present.

The ratio of $PCUS_t/BHUS_t$ was detrended for all four quarters. The threshold point in 1975 was indicated by plots of the ratio against time. The coefficients from these regressions were fixed in the pig crop equation in subsequent estimation (see Table 1, eq. 4). The ratio of

$BGSUS_t/PCUS_{t-2}$ was detrended only in the fourth quarter. The same threshold point of 1975 appeared to exist in this quarter. The first three quarters' coefficients were restricted to the quarterly sample means in Table 2. In the fourth quarter the coefficients were restricted to the preliminary regression results (see Table 1, eq. 5).

The fundamental determinant of pork production is the size of the breeding herd. However, in the short run producers have discretion in adjusting marketing times. These short-run supply adjustments are represented in the equations that determine the live weight of barrows and gilts (6) and the live weight of sows (7). The estimated coefficients in both equations indicate that producers feed the hogs for longer time periods in response to higher output prices, other things equal. Higher feed costs reduce the average slaughter weights for barrows and gilts and for sows. Surprisingly, the live weight of sows shows more response to input and output prices than does the live weight of barrows and gilts. Seasonality is accounted for with quarterly dummy variables.

Total domestic pork production (8) is derived through an identity that equals the sum of barrow and gilt slaughter and sow slaughter multiplied by their respective average live weights. Boar slaughter is not explicitly introduced in the identity because it is a minor component of total slaughter. Domestic pork production, which is in live weight, is transformed into carcass weights in the equation that determines total commercial pork production (9). The logarithm of the time trend captures the carcass improvements, more usable carcass per pound of live weight hogs marketed. The coefficients on domestic pork production incorporate boar slaughter, typically proportional to domestic pork production.

Demand Component

Price determination of the model is assumed to occur at the retail level. As Fox (1953) observed, livestock production is essentially fixed in the short run, and hence the determination of the retail price depends on the location of the demand curve. The retail price is linked to the farm price through a margin equation. The other demand component determined behaviorally is closing cold-storage stocks. Domestic disappearance, which determines per capita pork consumption, is derived from the market closing identity. Again, the results for the demand components are provided in Table 3.

The prevalent form of demand functions used in livestock sector models is static and ad hoc in nature, and hence does not follow the theory of consumer behavior. In part, this reflects the rejection of the axioms of consumer behavior in most food demand studies at the market level (Deaton and Muellbauer 1980). The reasons for the rejection of the Slutsky conditions are many, but they may be related to the assumption of instantaneous consumer adjustment to changes in relative prices and income implied by the static approach, as well as to problems of aggregation.

Consumers often react with some delay to changes in relative prices and income. Habit formation in consumption may lead to delayed responses and thus extend an adjustment process toward a new equilibrium (Pollack and Wales 1980; Blanciforti et al. 1986; Heien 1982; Johnson et al.

1984). This inertia in consumption patterns implies that consumption dynamics should be explicitly introduced into the specification of the demand functions.

The retail demand function used in the model incorporates persistence in consumption. The specification of the model begins with a general set of stochastic difference equations, obtaining their final form, and then applying an error correction method similar to the approach used by Anderson and Blundell (1983). A log-linear model is used in spite of significant theoretical limitations (LaFrance 1986). The log-linear functional form is used mainly for computational and expositional convenience.

The general specification developed from the final form of the set of stochastic difference equations admits persistence in consumption patterns and explicitly delineates both short- and long-run behavior:

$$\Delta_4 \log Q_t = D + \sum_{j=1}^{K} \beta_j \, \Delta_4 \log X_{jt}$$

$$+ (\alpha - 1)[\log Q_{t-4} - \sum_{j=1}^{K} \epsilon_{ij} \log X_{t-4}] + e_t.$$

Dynamics in consumption enter through a fourth-order lag on the quantity consumed, Q_t, and in the other demand conditioning variables, X_t. The short-run behavior is captured in the parameters β_j, and the speed of the adjustment process is governed by $\alpha - 1$. The long-run parameters are ϵ_{ij}. The fourth-order lag structure was chosen because of the periodicity of the data. The fourth-order difference is Δ_4.

The terms within the brackets continually move consumption levels to the long-run equilibrium. If the adjustment parameter, $\alpha - 1$, is negative, and if long-run consumption, Q_{t-4}, is above the level implied by the conditioning variables, X_{t-4}, current consumption declines. This in essence is the error correction mechanism in which consumers adjust consumption levels toward long-run equilibrium. Also, since the log-linear specification was used, the parameters β_j and ϵ_{ij} can be interpreted as the short- and long-run elasticities, respectively. Details on the development of this general specification can be found in Kesavan et al. (1989).

The general error correction structure was used to estimate the <u>retail pork demand</u> (10) within a system of demand equations, including beef and chicken (Table 3). Thus, the retail prices of beef and chicken enter as conditioning variables in the pork demand equation. Other conditioning variables included were per capita food expenditure and the consumer price index of food, a proxy for all other competing food products. This set of conditioning variables implies a two-stage budgeting process (Brown and Heien 1972). Quarterly dummy variables were included to capture the seasonality in demand.

Habit formation in consumption, combined with a gradual adjustment process, implies that the axioms of consumer behavior need not apply to short-run behavior. At most, consumers would be aware of relative price changes in the short run. Thus, the homogeneity restriction was imposed on the short-run parameters. In the long run, consumers have the ability to fully discern relative price and income shifts, and thus were presumed to adhere to the precepts of consumer behavior. Hence, the homogeneity and symmetry restrictions were imposed for long-run behavior. However, in the formulation of the model the restrictions imposed on the long-run behavior restrict the short-run parameters.[2] This forces a correspondence between short- and long-run behavior and places restrictions on dynamic behavior.

The results, presented in Table 3, have the anticipated signs except for the short-run coefficient on the retail price of chicken and the derived long-run coefficient on the price index of other foods. The negative short-run, cross-price elasticity for chicken corresponds to previous results (Moschini and Meilke 1988); in the long run it becomes positive. The negative elasticity with the price index of foods suggests a complementary relationship with pork consumption in the long run. The estimates also suggest, as expected, that the own- and cross-price effects increase as consumers have time to adjust to relative price changes. This behavior holds true for the expenditure elasticity as well.

The estimated adjustment coefficient that governs the movement to long-run equilibrium for pork was -0.25. The coefficient was near the midpoint of the same coefficients in the beef and chicken consumption patterns. Beef demonstrated the least amount of persistence, while chicken consumption had the highest level of persistence in consumption.

The <u>retail-farm margin</u> (11) links the retail price to the farm-level barrow and gilt price. The margin specification developed by Wohlgenant and Mullen (1987) recognizes that the margin may be affected both by changes in output and in retail price movements, as well as by changes in the prices of inputs of marketing services. The margin equation does not force a constant relationship between the retail price and the marketing margin across quarters.

The margin is posited as a function of the retail price, the retail price multiplied by the per capita quantity produced, and an index of marketing costs. The marketing cost index includes both meat packers' wage rate and a measure of fuel and utilities cost. Hayenga et al. (1985, 51) note that "labor costs comprise nearly one-half of meat packers' operating costs." The fuel and utility index reflects changes in general overhead costs. Also included in the specification is the price of pork by-products, a residual obtained in the slaughter process. The lagged dependent variable captures stickiness in the retail-farm margin. All components in the equation were deflated by the consumer price index.

As expected, the retail price and marketing costs have a positive effect on the retail-farm margin. The total value of production also had a positive effect on the margin. This confirms the notion that as volume processed increases, the percentage markup also increases. Changes in the price of pork by-products have a significant negative effect on the marketing margin. Packers bid up farm prices in response to higher by-product prices. The results also suggest that there is significant stickiness in the marketing margin. This follows from the general rigidity of wholesale and retail pricing structures (Hayenga et al. 1985). The <u>price of barrows and gilts--seven markets</u> (12) is the difference between the retail price and the retail-farm margin.

The other demand component is closing cold-storage stocks (13). It is a function of the retail price of pork, total commercial pork production, and the level of beginning stocks. The retail price of pork has a negative effect on ending stocks because as prices increase, packers are less willing to hold excessive stocks. Total commercial production and beginning stocks have a positive influence on ending stocks because as total available supply increases, given existing demand, ending supply will invariably increase. Beginning stocks (14) are simply the previous period's ending stocks.

The market clearing identity equates pork supply and demand. From this identity total pork domestic disappearance (15) is obtained. Exogenous supply and demand components included in the identity are on-farm pork production, PFPD; exports, EXPTS; imports, IMPTS; shipments, SHPMTS; and military use, MILUSE. Domestic disappearance was divided by the U.S. population and multiplied by the carcass-retail weight conversion ratio to obtain per capita pork consumption (16).

Definitions of the variables and details on their construction and data sources appear in Table 4.

Validation and Evaluation

Validation exercises establish how well the behavior of the model corroborates the behavior of the system modeled. The estimated equations provide approximations of the supply and demand components for the pork sector. Thus, before these approximations can be used to evaluate the reaction of the pork sector to policy shifts and technological advances, the integrity of the system must be checked.

The ability of the model to track the historical behavior of the various supply and demand components is examined first. Historical simulation statistics, specifically the root-mean-percent square error (RMPSE), are presented for dynamic and static simulations. Next, the implied elasticities of the model are compared with other econometric models of the pork sector. The elasticities are derived with the nonlinear simulation techniques using the approach of Fair (1980). Last, the forecast performance of the model is evaluated with an ex post forecast for the four quarters in 1987.

In Table 5 the RMPSEs are presented for selected endogenous variables. This is a measure of the absolute deviations of the predicted values from the historical values expressed in percentage terms (Pindyck and Rubinfeld 1981). The dynamic simulations use predicted values of the endogenous variables in the lag structure. The static simulation uses the actual values of the endogenous variables in the lag structure. Both simulations were conducted over the sample period.

The historical simulation statistics indicate the model provides an adequate representation of the pork sector. The simulation error statistics for the additions to the breeding herd and the closing inventory of cold-storage stocks are larger than might be desired. But data for additions to the breeding herd are derived from the breeding herd inventory identity, and thus they incorporate the errors associated with the interpolated breeding herd and the sow slaughter data. The simple specification used in the closing stocks equation may not be an adequate representation of this minor and highly seasonal demand component.

With linear models the dynamic properties of systems can be examined through the reduced form equations of the estimated model. Mean paths, multipliers, and elasticities can be obtained analytically from the reduced form equations. However, with nonlinear models, as for the pork model, the reduced form expressions cannot be analytically derived. Also, closed form expressions of impact and dynamic multipliers are not generally known.

Fair (1980) illustrates the use of simulation methods to evaluate the dynamic behavior of nonlinear models. In deriving the dynamic behavior of the pork model, these simulation techniques were applied with three simplifying assumptions. First, all stochastic error terms were set to zero; second, the estimated parameters were assumed to be known with certainty; and third, all exogenous variables were set at their means.

Briefly, the steps to derive the approximate dynamic multipliers are as follows. First, a baseline solution was obtained. The baseline solution was obtained by setting all exogenous variables to their sample-mean values (1967-1986 averages). The model was simulated until the endogenous variables reached constant levels. This baseline of steady-state solution was then used for comparison of simulations in which selected exogenous variables were perturbed. Feed cost, interest rate, and retail beef and chicken prices were increased by a sustained 10 percent from their sample-mean values. The model was simulated again for each of these four exogenous shocks and was allowed to converge to a new steady-state solution. The new solution typically was obtained after 30 quarters. Percentage changes from the baseline for the feed cost, interest rate, retail beef price, and retail chicken price simulations are provided in Tables 6 through 9, respectively.

The responses evaluated for the selected endogenous variables indicate that pork supply response to changes in these exogenous factors is very inelastic in the short run, and that it becomes less so as the effects of movements in gilt additions and sow slaughter move through the system. The biological constraints on production prohibit instantaneous increases in supply without an underlying increase in the breeding herd. Thus, the supply response does not become appreciable until after the first year of the sustained shock.

Of interest in Table 6 is that the sustained 10 percent increase in feed cost leads to about a 10 percent increase in the farm price and a 4.87 percent reduction in supply after the model equilibriates. The sustained 10 percent increase in the retail beef price leads to a 9.5 percent increase in pork supply, but to no change in the farm price. Similar response estimates are found in the other tables. These results indicate that the supply response of pork producers nearly eliminates changes in the farm price in the longer run. Of course, these multipliers were simulated holding all other variables constant; thus, dynamic cross-commodity effects are ignored.

Comparison to Other Estimates

Supply elasticities for the CARD model and other selected pork sector models are provided in Table 10. The reported supply elasticity for the CARD quarterly pork model is derived from the response to a one-year increase in the farm-level pork price. Using only the supply component of the pork model, all exogenous variables were fixed at their 1984-1986 mean values. The reported short-run supply elasticity of 0.03 is the average first-year supply response to a 1 percent increase in farm price. The long-run elasticity of 0.50 is the final convergent response to the shock in the farm price. This convergent value is reached by the third year after the initial price shock.

Differences among the estimated supply elasticities exist for many reasons. The period of study is one reason. Differences in the method of calculation of the elasticity can also affect its value. Analytical approaches derived directly from estimated parameters may provide a different measure of supply response compared to the simulation approach used in this study. Nevertheless, the estimated supply elasticity for the CARD model is quite similar to previous work.

Elasticities for the complete livestock demand system are presented in Table 11. In general, the demand elasticities become more elastic in the long run. This is intuitively appealing since consumers can more fully adjust to relative price and income changes. The pork demand elasticities have the anticipated signs in the long run. The short-run, cross-price elasticity with chicken is negative but increases to a positive value in the long run. These estimates can be compared to those from earlier studies. Table 12 gives demand elasticities from selected demand studies. The demand elasticities in the CARD model are generally in line with these previous results.

An ex post forecast was made for the four quarters of 1987. The RMPSEs for the forecast are provided for selected endogenous variables in Table 13. These results are somewhat disappointing, but not entirely surprising. Given the high barrow and gilt prices relative to feed costs during the period, the model predicts a larger breeding herd buildup than observed. Thus, the model overpredicted the level of additions and underpredicted the level of sow slaughter. The slow buildup in the breeding herd during 1987 was unprecedented given the relationship that existed between input and output prices. In part, the observed lower rate of expansion may be due to credit limitations and the general uncertainty about the market. Nevertheless, the model does project total supply and price movements adequately. The decline in sow slaughter was partially offset by increases in barrow and gilt slaughter and in slaughter weights.

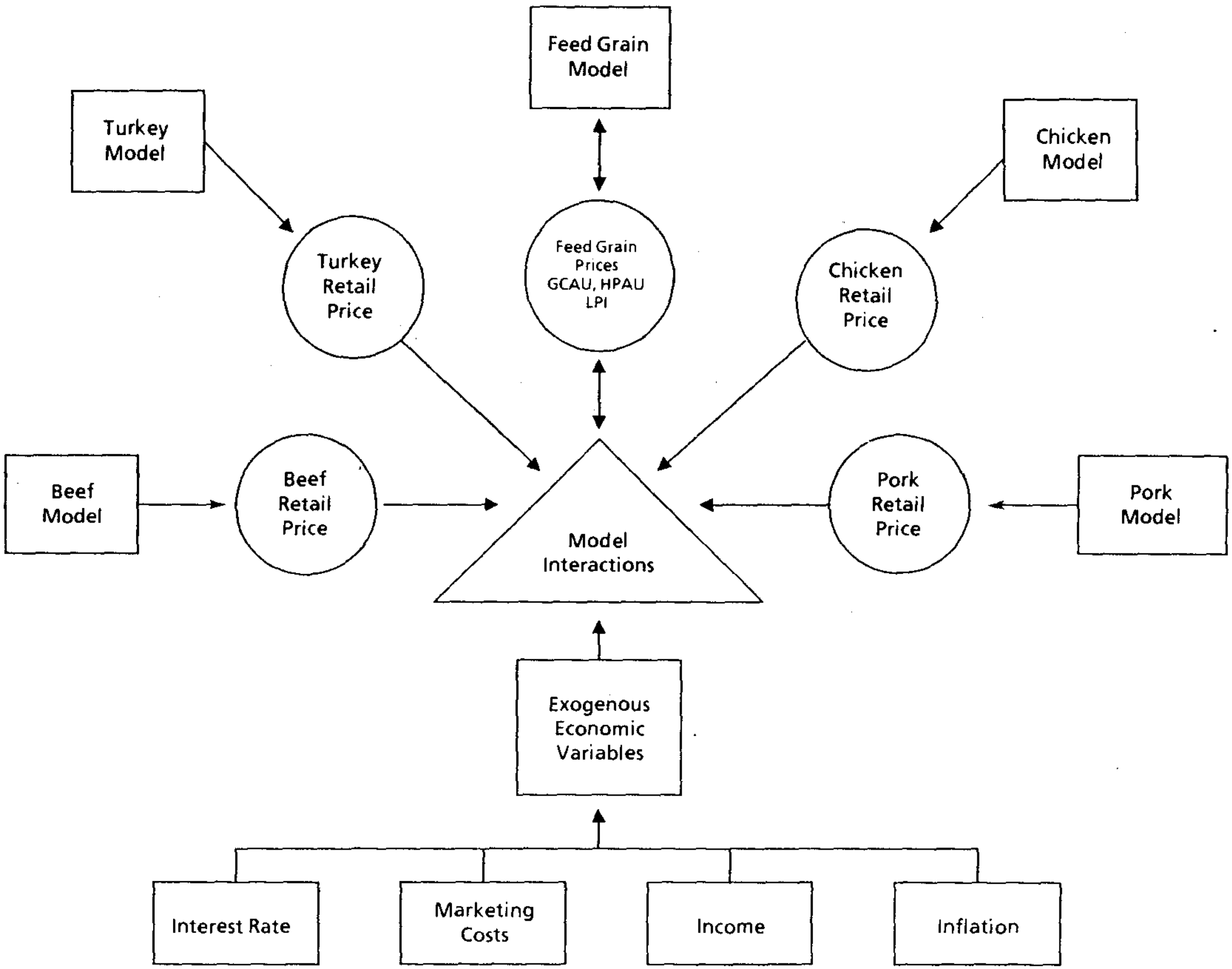

Figure 1. Livestock sector model linkages.

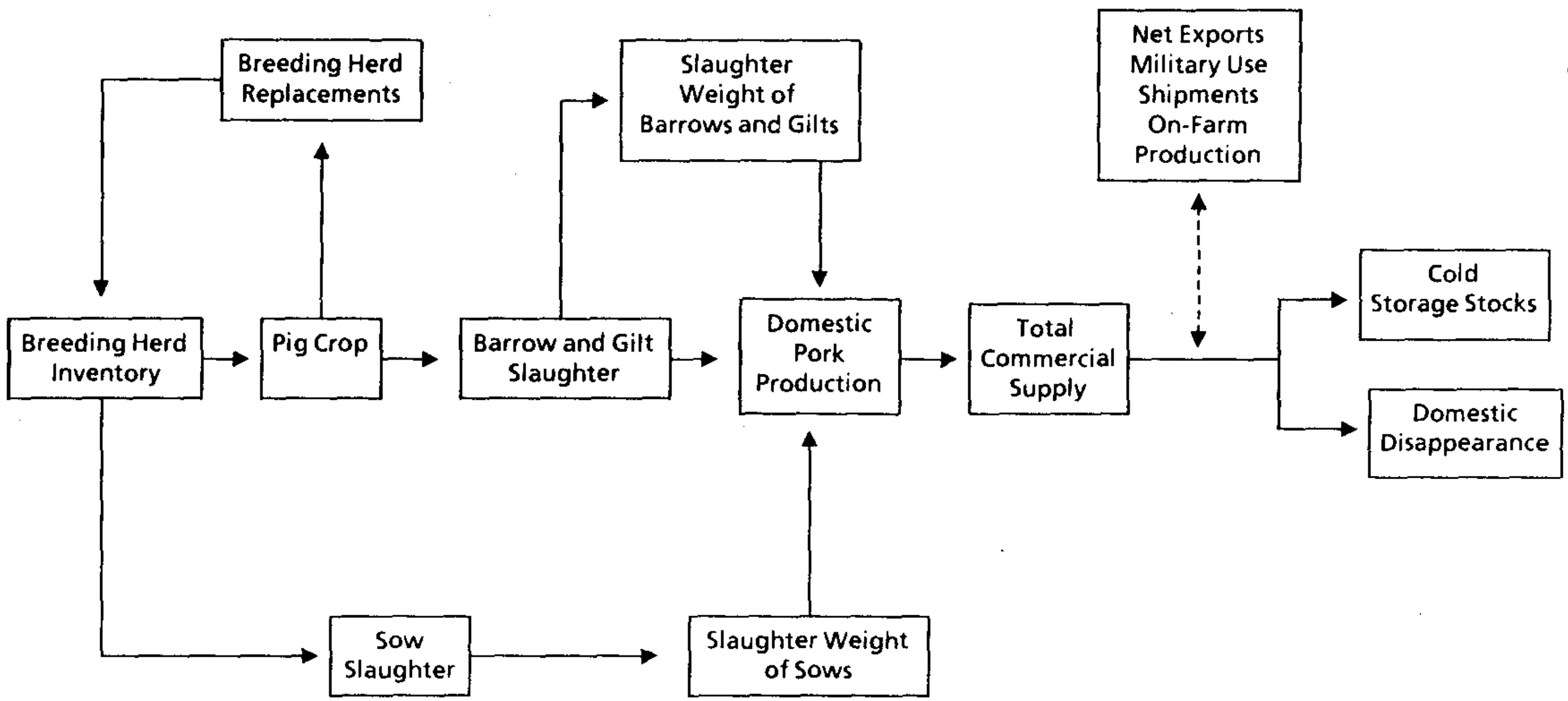

Figure 2. Supply components of the U.S. quarterly pork model.

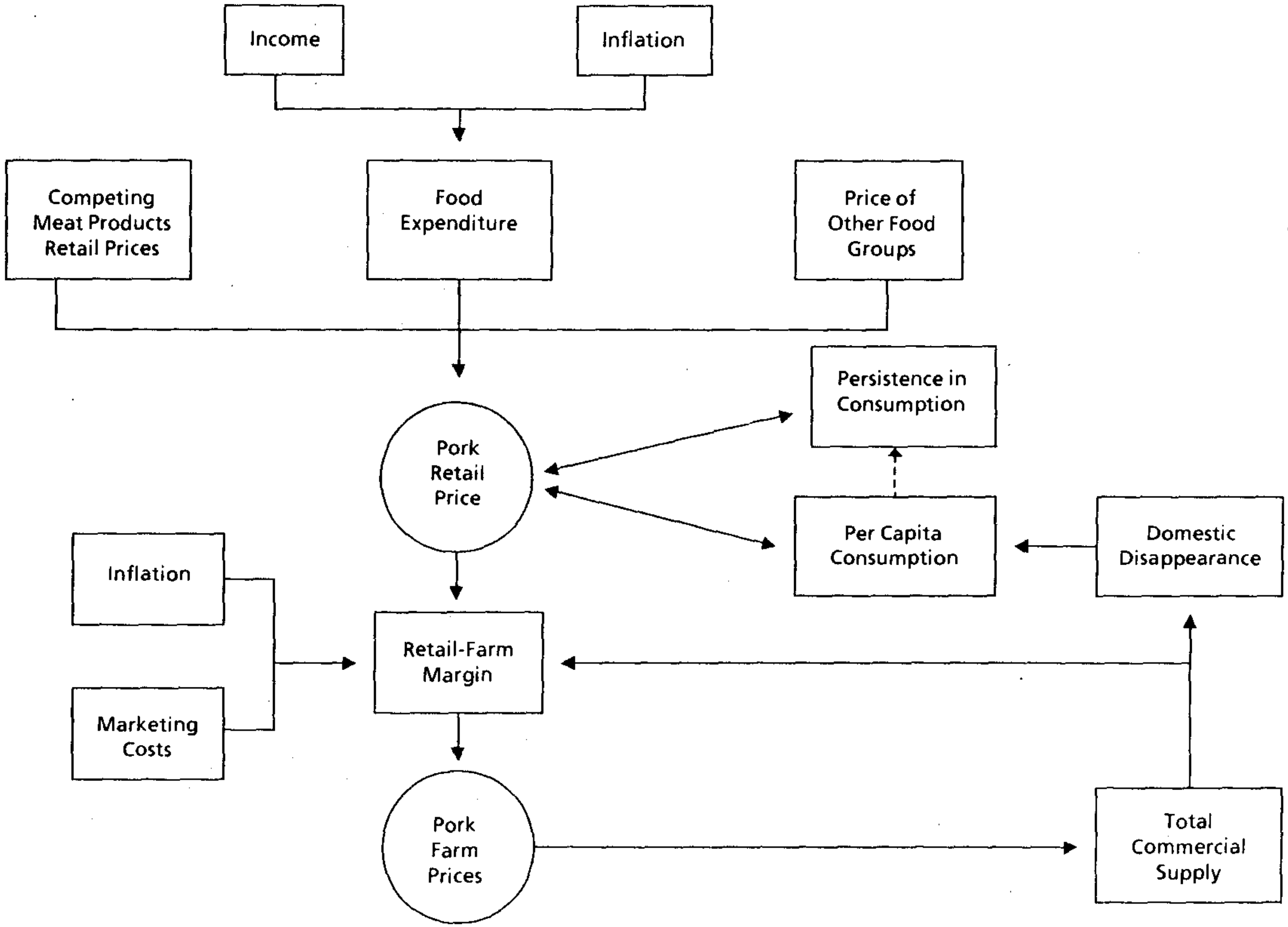

Figure 3. Price determination of the U.S. quarterly pork model.

Table 1. Estimates of supply components

(1) Additions to the breeding herd (NLS)[a,b]

$$ABHUS_t = 0.5\ PCUS_{t-2}/\{1 + EXP[\underset{(7.74)}{2.43136} - \underset{(-0.17)}{0.0199}\ D2 - \underset{(-5.00)}{0.56861}\ D3$$

$$+ \underset{(2.89)}{0.36936}\ D4 - \underset{\substack{(-0.19)\\ [0.05]}}{0.04980}(FPPK/PKFC)_{t-1} - \underset{\substack{(-2.05)\\ [0.59]}}{0.53759}(FPPK/PKFC)_{t-2}$$

$$+ \underset{\substack{(1.33)\\ [-0.10]}}{0.02596}\ RIFCL_{t-1} - \underset{\substack{(-0.38)\\ [0.03]}}{0.0077366}\ RIFCL_{t-2} + \underset{(2.36)}{0.19350}\ LT65]\}$$

S/M = 0.016[c] D.W. = 2.03[d]

(2) Sow slaughter (NLS)

$$SSUS_t = BHUS_{t-1}/\{1 + EXP[\underset{(14.08)}{1.3748} - \underset{(-1.53)}{0.06196}\ D2 - \underset{(-8.07)}{0.30388}\ D3$$

$$- \underset{(-6.76)}{0.25581}\ D4 + \underset{\substack{(1.98)\\ [-0.20]}}{0.16258}(FPPK/PKFC)_t + \underset{\substack{(1.37)\\ [-0.15]}}{0.12021}(FPPK/PKFC)_{t-1}$$

$$- \underset{\substack{(-1.30)\\ [0.03]}}{0.008185}\ RIFCL_t - \underset{\substack{(-0.57)\\ [0.01]}}{0.0035074}\ RIFCL_{t-1} + \underset{(4.63)}{0.12409}\ LT65]\}$$

S/M = 0.009 D.W. = 1.22

(3) Breeding herd inventory

$$BHUS_t = BHUS_{t-1} + ABHUS_t - SSUS_t$$

(4) Pig crop (RLS)

$$PCUS_t = (2.124536 + 0.882383\ LOGT75 - 2.148498\ DUM75) * BHUS_t * D1$$

$$+ (3.136823 + 0.853952\ LOGT75 - 2.377543\ DUM75) * BHUS_t * D2$$

$$+ (2.384821 + 1.111765\ LOGT75 - 2.730906\ DUM75) * BHUS_t * D3$$

$$+ (2.443753 + 1.276033\ LOGT75 - 3.233141\ DUM75) * BHUS_t * D4$$

S/M = 0.039 D.W. = N/A

Table 1. Estimates of supply components (continued)

(5) Barrow and gilt slaughter (RLS)

$$BGSUS_t = (0.883544\ D1 + 0.884334\ D2 + 0.936344\ D3 + 0.711681\ D4 + 0.153571\ LOGT75 * D4 - 0.313148\ DUM75 * D4) * PCUS_{t-2}$$

S/M = 0.033

(6) Live weight of barrows and gilts (GLS)

$$LWBG_t = \underset{(113.4)}{233.159}\ D1 + \underset{(121.8)}{237.967}\ D2 + \underset{(106.9)}{229.787}\ D3 + \underset{(113.8)}{236.225}\ D4 + \underset{\substack{(1.57)\\ [0.012]}}{2.3315}(FPPK/PKFC)_t$$

S/M = 0.0089 $\qquad u_t = \underset{(-8.19)}{-0.694} * u_{t-1} + \epsilon_t$

(7) Live weight of sows (GLS)

$$LWS_t = \underset{(65.6)}{438.098}\ D1 + \underset{(69.2)}{440.443}\ D2 + \underset{(60.7)}{421.501}\ D3 + \underset{(64.6)}{435.501}\ D4 + \underset{\substack{(2.73)\\ [0.034]}}{12.597}(FPPK/PKFC)_t$$

S/M = 0.014 $\qquad u_t = \underset{(-10.09)}{-0.765} * u_{t-1} + \epsilon_t$

(8) Total domestic pork production

$$PPF_t = BGSUS_t * LWBG_t + SSUS_t * LWS_t$$

(9) Total commercial production (GLS)

$$TOTSPK_t = \underset{\substack{(58.2)\\ [0.90]}}{0.6151}(PPF_t/1000) + \underset{(5.91)}{141.468}\ LT65$$

S/M = 0.015 $\qquad u_t = \underset{(-11.64)}{-0.798} * u_{t-1} + \epsilon_t$

[a]Asymptotic t-statistics are in parentheses.

[b]Elasticities evaluated at sample means are in brackets.

[c]S/M equals the standard error divided by the sample mean of the dependent variable.

[d]D.W. is the Durbin-Watson statistic.

Table 2. Quarterly means and standard deviations of biological ratios for the time period 1967.00 - 1986.75

	Quarter			
Ratio	1	2	3	4
$PCUS_t/BHUS_t$	2.307551 (0.243704)[a]	3.143043 (0.18710)	2.621907 (0.284166)	2.668298 (0.29727)
$BGSUS_t/PCUS_{t-2}$	0.883544 (0.031550)	0.884334 (0.02741)	0.936344 (0.040703)	0.784282 (0.06820)

NOTE: 1967.00 represents the first quarter of 1967, etc.

[a]Values in the top row represent quarterly means. Values in parentheses are standard deviations of quarterly means.

Table 3. Estimates of demand components

(10) Retail pork demand (ITSUR)[a,b]

$$LOG(PCPK4_t) = \underset{(6.95)^c}{2.352} - \underset{(-4.20)}{0.0687}\ D2 - \underset{(-4.09)}{0.08003}\ D3 - \underset{(-0.36)}{0.00757}\ D4$$

$$+ LOG(PCPK4_{t-4}) + 0.421[LOG(RPBF4_t) - LOG(RPBF4_{t-4})]$$

$$- \underset{(-15.08)}{0.6958}[LOG(RPPK_t) - LOG(RPPK_{t-4})]$$

$$- \underset{(1.42)}{0.06184}[LOG(RPCK_t) - LOG(RPCK_{t-4})]$$

$$+ 0.14183[LOG(CPIFOOD_t) - LOG(CPIFOOD_{t-4})]$$

$$+ \underset{(1.13)}{0.19479}[LOG(FEXP_t) - LOG(FEXP_{t-4})]$$

$$+ (0.25 - 1)^{d} * [LOG(PCPK4_{t-4})$$

$$- \underset{(7.81)}{0.61894}\ LOG(RPBF4_{t-4}) + \underset{(-8.64)}{0.59812}\ LOG(RPPK_{t-4})$$

$$- 0.13104\ LOG(RPCK_{t-4}) - 0.67990\ LOG(FEXP_{t-4})$$

$$+ 0.83176\ LOG(CPIFOOD_{t-4})]$$

S/M = 0.012[e] D.W. = N/A[f]

(11) Retail-farm margin (OLS)

$$MARGIN_t = \underset{[0.54]}{\underset{(11.91)}{0.36234}}(RPPK/CPI)_t * D1 + \underset{[0.53]}{\underset{(11.83)}{0.36064}}(RPPK/CPI)_t * D2$$

$$+ \underset{[0.57]}{\underset{(12.73)}{0.37185}}(RPPK/CPI)_t * D3 + \underset{[0.56]}{\underset{(12.20)}{0.37069}}(RPPK/CPI)_t * D4$$

$$+ \underset{[0.10]}{\underset{(2.50)}{0.00379}}(RPPK/CPI)_t * (TOTSPK/POPN4)_t + \underset{[0.02]}{\underset{(1.50)}{0.0000551}}\ MKTCOST_t$$

$$- \underset{[-0.04]}{\underset{(-2.97)}{0.00768}}(PKBYP/CPI)_t + \underset{[0.40]}{\underset{(8.99)}{0.4041}}\ MARGIN_{t-1}$$

S/M = 0.024 D.W. = N/A

Table 3. Estimates of demand components (continued)

(12) Price of barrows and gilts--seven markets

$$FPPK_t = (RPPK_t - MARGIN_t * CPI_t) * 100$$

(13) Closing cold-storage stocks (OLS)

$$ENDSTKS_t = \underset{(0.08)}{2.8564\ D1} + \underset{(0.05)}{1.9272\ D2} - \underset{(-2.73)}{93.846\ D3} - \underset{(-0.01)}{0.31569\ D4}$$

$$- \underset{\substack{(-1.99)\\ [-0.00086]}}{0.1854\ RPPK_t} + \underset{\substack{(3.71)\\ [0.55]}}{0.04154\ TOTSPK_t} + \underset{\substack{(7.78)\\ [0.62]}}{0.6222\ BNGSTKS_t}$$

S/M = 0.11 D.W. = N/A

(14) Beginning stocks

$$BNGSTKS_t = ENDSTKS_{t-1}$$

(15) Domestic disappearance

$$TOTDPK_t = TOTSPK_t + PFPD_t - ENDSTKS_t + BNGSTKS_t - EXPTS_t + IMPTS_t - SHPMTS_t - MILUSE_t$$

(16) Per capita pork consumption

$$PCPK4_t = (TOTDPK/POPN4)_t * PCONVERT$$

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[a]The retail pork demand was estimated with the fourth-order difference of per capita pork consumption on the right-hand side.

[b]The retail pork demand was inverted to obtain the logarithm of the retail price of pork in simulations.

[c]Asymptotic t-statistics are in parentheses. Elasticities in the retail demand equation are the coefficients; elsewhere elasticities, evaluated at sample means, appear in brackets.

[d]The adjustment coefficients were restricted.

[e]S/M equals the standard error divided by the sample mean of the dependent variable.

[f]D.W. is the Durbin-Watson statistic.

Table 4. U.S. quarterly pork model variables and their sources

Variable	Units	Label	Source[a]
Breeding herd inventory	1,000 head	BHUS	USDA, Livestock and Poultry
Sow slaughter	1,000 head	SSUS	USDA, Livestock and Poultry
Additions to the breeding herd	1,000 head	ABHUS	BHUS-LAG(BHUS) + SSUS
Barrow and gilt slaughter	1,000 head	BGSUS	USDA, Livestock Slaughter
Pig crop	1,000 head	PCUS	USDA, Livestock and Poultry
Closing cold-storage stocks	million pounds	ENDSTKS	USDA, Livestock and Poultry
Beginning stocks	million pounds	BNGSTKS	USDA, Livestock and Poultry
Price of barrows and gilts --seven markets	dollars/cwt	FPPK	USDA, Livestock and Poultry
Retail price of pork	dollars/pound	RPPK	USDA, Livestock and Poultry
Pork retail-farm margin	dollars/cwt	MARGIN	100 * RPPK-FPPK
Total domestic pork production	million pounds	PPF	USDA, Livestock and Poultry
Total pork domestic disappearance	million pounds	TOTDPK	USDA, Livestock and Poultry
Total commercial pork production	million pounds	TOTSPK	USDA, Livestock and Poultry

Table 4. U.S. quarterly pork model variables and their sources (continued)

Variable	Units	Label	Source[a]
Per capita pork consumption	pounds	PCPK4	USDA, Livestock and Poultry
Pork exports	million pounds	EXPTS	USDA, Livestock and Poultry
Pork imports	million pounds	IMPTS	USDA, Livestock and Poultry
Pork military use	million pounds	MILUSE	USDA, Livestock and Poultry
Pork on-farm production	million pounds	PFPD	USDA, Livestock and Poultry
Pork shipments	million pounds	SHPMTS	USDA, Livestock and Poultry
Live weight of barrows and gilts	pounds	LWBG	USDA, Livestock and Meat Statistics; Personal correspondence, U.S. Department of Agriculture
Live weight of sows	pounds	LWS	USDA, Livestock and Meat Statistics; Personal correspondence, U.S. Department of Agriculture
Carcass-retail weight conversion ratio		PCONVERT	USDA, Livestock and Poultry
Index of meat packers hourly earnings	1967 = 100	IMPHRE	U.S. Department of Commerce, Employment and Earnings
Producer price index of fuel and power	1967 = 100	PPIFP	U.S. Department of Commerce, Survey of Current Business
Marketing cost		MKTCOST	$\frac{0.5(PPIFP+IMPHRE)}{CPI}$
Trend variable	1965 = 1	T65	
Log of trend variable		LT65	LOG(T65)

Table 4. U.S. quarterly pork model variables and their sources (continued)

Variable	Units	Label	Source[a]
Dummy variable, T65	If < 1975 = 0 If ≥ 1975 = LT65	LOGT75	
Dummy variable, 1975	If < 1975 = 0 If ≥ 1975 = 1	DUM75	
Seasonal dummy variables		D1, D2, D3, D4	
Consumer price index	1967 = 100	CPI	U.S. Department of Commerce, Survey of Current Business
Corn price	dollars/bushel	PCO4	USDA, Agricultural Prices
Soymeal price, Decatur	dollars/ton	PSOYB	USDA, Feed
Pork feed cost index		PKFC	10.33 PCO4 + 0.059 PSOYB
Interest rate on feeder cattle loans	percent	IFCL	Fed. Reserve Bank of Chicago, Agricultural Letter
Real interest rate	percent	RIFCL	IFCL-INFL
Inflation rate	percent	INFL	$100\{EXP[4 * LOG (CPI_t/CPI_{t-1})] - 1\}$
U.S. population	millions	POPN4	U.S. Department of Commerce, Survey of Current Business
Food consumption expenditures (not seasonally adjusted)	billion dollars	FOODEXP	Personal correspondence, U.S. Department of Commerce
Per capita personal consumption expenditures--food	dollars/person	FEXP	$\frac{FOODEXP * 1000}{POPN4}$
Consumer price index--food	1967 = 100	CPIFOOD	USDA, Agricultural Outlook

[a] See References for further information on data sources.

Table 5. Historical simulation statistics

Variable	Label	Dynamic RMPSE[a]	Static RMPSE
Additions to the breeding herd	ABHUS	66.25	57.24
Sow slaughter	SSUS	18.48	15.48
Breeding herd inventory	BHUS	8.54	3.83
Pig crop	PCUS	8.18	5.06
Barrow and gilt slaughter	BGSUS	7.74	3.41
Live weight of barrows and gilts	LWBG	1.27	1.16
Live weight of sows	LWS	2.32	2.17
Total domestic pork production	PPF	7.52	3.97
Total commercial production	TOTSPK	7.37	4.38
Retail pork price	RPPK	10.13	6.16
Retail-farm margin	MARGIN	8.24	3.98
Price of barrows and gilts--seven markets	FPPK	18.24	13.82
Closing cold-storage stocks	ENDSTKS	31.65	15.89
Domestic disappearance	TOTDPK	7.04	4.13
Per capita pork consumption	PCPK4	7.04	4.13

NOTE: Historical simulation was made over the sample period, 1967.00-1986.75.

[a]RMPSE is the root-mean-percent square error.

Table 6. Selected pork model variable responses to a 10 percent increase in feed costs (PKFC)

PERIOD	TOTSPK	BGSUS	SSUS	PCUS	ABHUS	FPPK	RPPK
			(Percentage change)				
1	-0.04	0.00	1.54	-0.20	0.00	0.12	0.06
2	-0.01	0.00	2.50	-0.59	-0.43	0.00	0.01
3	-0.19	-0.20	2.04	-1.62	-5.73	0.51	0.26
4	-0.56	-0.59	0.78	-2.54	-6.14	1.42	0.76
5	-1.46	-1.62	-0.61	-3.36	-6.81	3.69	2.02
6	-2.27	-2.54	-1.95	-4.05	-7.14	5.32	3.18
7	-2.99	-3.36	-3.03	-4.54	-6.74	6.69	4.27
8	-3.59	-4.05	-3.84	-4.89	-6.54	7.77	5.24
9	-4.02	-4.54	-4.44	-5.14	-6.29	8.57	6.05
10	-4.33	-4.89	-4.85	-5.30	-6.07	9.08	6.68
15	-4.87	-5.51	-5.52	-5.55	-5.62	9.96	8.14
20	-4.91	-5.56	-5.56	-5.55	-5.53	10.05	8.46
25	-4.89	-5.53	-5.54	-5.52	-5.51	10.03	8.50
30	-4.87	-5.52	-5.52	-5.51	-5.51	10.01	8.49

NOTE: Values represent approximate total elasticities with respect to feed costs. The elasticities allow for demand and supply adjustments within the pork sector but exclude cross-commodity adjustments. The values were generated through dynamic simulation at the 1984-1986 mean values of the exogenous variables.

Table 7. Selected pork model variable responses to a 10 percent increase in interest rate (RIFCL)

PERIOD	TOTSPK	BGSUS	SSUS	PCUS	ABHUS	FPPK	RPPK
			(Percentage change)				
1	-0.01	0.00	0.30	-0.04	0.00	-0.03	-0.02
2	-0.01	0.00	0.40	-0.22	-0.97	-0.03	-0.02
3	-0.03	-0.04	0.20	-0.35	-0.74	0.08	0.03
4	-0.18	-0.22	-0.01	-0.47	-0.92	0.49	0.25
5	-0.29	-0.35	-0.22	-0.56	-0.96	0.69	0.40
6	-0.40	-0.47	-0.37	-0.63	-0.83	0.87	0.55
7	-0.48	-0.56	-0.48	-0.67	-0.80	1.01	0.67
8	-0.54	-0.63	-0.55	-0.70	-0.75	1.09	0.77
9	-0.58	-0.67	-0.60	-0.71	-0.71	1.14	0.84
10	-0.60	-0.69	-0.62	-0.72	-0.69	1.17	0.90
15	-0.63	-0.73	-0.65	-0.73	-0.65	1.20	1.00
20	-0.63	-0.73	-0.65	-0.72	-0.65	1.21	1.02
25	-0.62	-0.72	-0.65	-0.72	-0.65	1.20	1.02
30	-0.62	-0.72	-0.65	-0.72	-0.65	1.20	1.02

NOTE: Values represent approximate total elasticities with respect to the interest rate. The elasticities allow for demand and supply adjustments within the pork sector but exclude cross-commodity adjustments. The values were generated through dynamic simulation at the 1984-1986 mean values of the exogenous variables.

Table 8. Selected pork model variable responses to a 10 percent increase in retail beef price (RPBF4)

PERIOD	TOTSPK	BGSUS	SSUS	PCUS	ABHUS	FPPK	RPPK
			(Percentage change)				
1	0.05	0.00	-1.85	0.24	0.00	10.93	5.86
2	0.00	0.00	-2.44	0.64	0.53	7.84	5.94
3	0.22	0.24	-1.34	1.78	7.25	5.83	5.62
4	0.60	0.64	-1.28	2.49	5.64	4.34	5.08
5	1.67	1.78	-1.22	3.38	5.52	18.32	12.67
6	2.20	2.49	-1.11	4.33	6.06	12.37	11.84
7	3.00	3.38	1.22	6.25	15.71	8.54	10.61
8	3.88	4.33	4.06	7.38	12.59	5.87	9.25
9	5.57	6.25	5.25	8.27	11.99	7.40	9.93
10	6.54	7.38	6.51	8.93	11.52	4.13	8.45
15	9.01	10.19	10.12	10.49	11.36	0.44	5.10
20	9.41	10.64	10.66	10.71	10.82	0.05	4.32
25	9.50	10.74	10.75	10.75	10.75	0.02	4.14
30	9.50	10.75	10.75	10.74	10.73	-0.01	4.08

NOTE: Values represent approximate total elasticities with respect to the retail beef price. The elasticities allow for demand and supply adjustments within the pork sector but exclude cross-commodity adjustments. The values were generated through dynamic simulation at the 1984-1986 mean values of the exogenous variables.

Table 9. Selected pork model variable responses to a 10 percent increase in retail chicken price (RPCK)

PERIOD	TOTSPK	BGSUS	SSUS	PCUS	ABHUS	FPPK	RPPK
			(Percentage change)				
1	-0.01	0.00	0.27	-0.04	0.00	-1.55	-0.83
2	0.00	0.00	0.35	-0.09	-0.08	-1.11	-0.84
3	-0.03	-0.03	0.19	-0.25	-0.99	-0.83	-0.80
4	-0.09	-0.09	-0.04	-0.35	-0.78	-0.63	-0.73
5	-0.21	-0.25	-0.55	-0.38	-0.76	1.66	0.49
6	-0.31	-0.35	-0.80	-0.35	-0.63	1.26	0.62
7	-0.33	-0.37	-0.68	-0.18	-0.66	1.01	0.66
8	-0.31	-0.35	-0.44	-0.06	0.43	0.80	0.64
9	-0.15	-0.18	-0.34	0.05	0.45	1.06	0.82
10	-0.05	-0.06	-0.20	0.13	0.46	0.67	0.70
15	0.28	0.32	0.31	0.38	0.51	0.11	0.32
20	0.36	0.41	0.41	0.42	0.44	0.02	0.20
25	0.38	0.43	0.43	0.43	0.43	0.01	0.17
30	0.38	0.43	0.43	0.43	0.43	0.00	0.16

NOTE: Values represent approximate total elasticities with respect to the retail chicken price. The elasticities allow for demand and supply adjustments within the pork sector but exclude cross-commodity adjustments. The values were generated through dynamic simulation at the 1984-1986 mean values of the exogenous variables.

Table 10. Comparison of selected pork supply response elasticities

Study	Data	Period	Supply elasticities	
Dean and Heady (1958)	semiannual	1938-1956	Spring	0.60
			Fall	0.30
		1924-1937	Spring	0.50
			Fall	0.28
Cromarty (1959)	annual	1929-1953		0.13
Harlow (1962)	annual	1949-1960		0.56 to 0.82
Meilke et al. (1974)	quarterly	1961-1971		0.43 to 0.48
Heien (1975)	annual	1950-1969		0.31
Marsh (1977)	annual	1953-1975		0.36
MacAulay (1978)	quarterly	1966-1976		0.50
Skold and Holt (1988)	quarterly	1967-1985		0.23
CARD (1989)	quarterly	1967-1986		0.03[a]
				0.50

[a]Denotes short-run elasticity.

Table 11. Estimated parameters for general dynamic demand model with homogeneity and symmetry imposed in the long run and homogeneity imposed in the short run (estimation period 1967-1986)

		Beef	Pork	Chicken	Expenditure	Lag adj.
Beef	SR	-0.52 (0.08)	0.23 (0.05)	-0.14 (0.05)	0.43 (0.20)[a]	0.33
	LR	-0.80 (0.07)	0.30 (0.06)	-0.028 (0.02)	1.06 (0.30)	
Pork	SR	0.42 (0.06)	-0.70 (0.05)	-0.06 (0.04)	0.19 (0.17)	0.25
	LR	0.62	-0.60 (0.07)	0.13 (0.07)	0.68 (0.23)	
Chicken	SR	0.06 (0.08)	0.19 (0.06)	-0.63 (0.06)	0.0004 (0.23)	0.17
	LR	-0.17	0.34	-1.05 (0.06)	1.24 (0.27)	

[a]Figures within parentheses indicate standard error.

Table 12. Summary of estimated elasticities by different studies

Study	Data	Period	Demand specifications	Elasticities Own-price[a]	Income/ expenditure	Cross-price[b]	
George and King (1971)	Time series and cross section	1946–1971 1965	Ad hoc	Beef −0.64 Pork −0.41 Chik −0.78	0.29 0.13 0.18	BP 0.08 PB 0.08 CB 0.20	BC 0.07 PC 0.04 CP 0.12
Christensen and Manser (1977)	Annual	1947–1971	Translog	Beef −0.96 Pork −0.76 Plty −0.98	1.33 0.78 0.78	BP −0.16 PB −0.08 CB −0.03	BC −0.07 PC 0.10 CP 0.12
Pope et al. (1980)	Annual	1950–1975	Ad hoc state adjustment model with Box-Cox transformation	Beef −0.68 Pork −0.81 Plty −0.61	0.61 0.38 0.58	BP 0.06 PB 0.32 CB 0.29	BC −0.01 PC 0.19 CP 0.24
Nyankori and Miller (1982)	Quarterly	1965.00–1979.50	Ad hoc	Beef −0.11 Pork −0.39 Chik −0.70	0.22 0.60 0.71	BP 0.41 PB 0.28 CB 0.54	BC −0.11 PC 0.20 CP −0.38
Wohlgenant and Hahn (1982)	Monthly	January 1965–June 1979	Dynamic model short run	Beef −0.49 Pork −1.25 Chik −0.14	0.51 0.27 0.49	BP 0.23 PB 0.60 CB 0.08	BC −0.20 PC 0.15 CP 0.0
			long run	Beef −0.43 Pork −0.84 Chik −0.30	0.45 0.18 1.06	BP 0.20 PB 0.40 CB 0.18	BC −0.17 PC 0.10 CP 0.02
Heien (1983)	Quarterly	1967.00–1979.75	Almost complete system	Beef −0.95 Pork −0.95 Bril −0.47	0.94 0.32 0.65	BP 0.13 PB 0.26 CB 0.24	BC 0.04 PC 0.04 CP 0.11
Chavas (1983)	Annual	1970–1979	Ad hoc model without structural change	Beef −0.86 Pork −0.71 Plty −0.54	0.56 0.44 0.05	BP 0.23 PB 0.22 CB 0.26	BC 0.07 PC 0.06 CP 0.22
			with structural change	Beef −0.62 Pork −0.72 Plty −0.58	0.18 0.43 0.28	BP 0.36 PB 0.22 CB 0.30	BC 0.08 PC 0.08 CP 0.001
Huang (1985)	Annual	1953–1983	Ad hoc model	Beef −0.62 Pork −0.73 Chik −0.11	0.45 0.44 0.36	BP 0.11 PB 0.19 CB 0.29	BC 0.06 PC 0.09 CP 0.26
Eales and Unnevehr (1987)	Annual	1965–1985	Almost ideal demand system	Beef −0.57 Pork −0.76 Chik −0.28	0.34 0.28 0.53	BP 0.17 PB 0.31 CB 0.25	BC 0.05 PC 0.007 CP 0.02

[a]Chik = chicken; Plty = poultry; and Bril = broilers.

[b]Nine possible cross-price elasticities exist for each study. Two-digit codes identify the percentage change in quantity variable (first digit) that changes with a 1 percent change in the price variable (second digit). The following code definitions are used: B = beef; P = pork; C = chicken, poultry, or broilers, whichever applies.

Table 13. Forecast performance statistics for pork model, 1987.00 to 1987.75

Variable	Label	RMPSE[a]
Additions to the breeding herd	ABHUS	0.60
Sow slaughter	SSUS	0.29
Breeding herd inventory	BHUS	0.18
Pig crop	PCUS	0.29
Barrow and gilt slaughter	BGSUS	0.07
Total commercial production	TOTSPK	0.13
Retail pork price	RPPK	0.07
Price of barrows and gilts--seven markets	FPPK	0.12
Closing cold-storage stocks	ENDSTKS	0.38

NOTE: 1987.00 to 1987.75 represents the first through fourth quarters of 1987.

[a]RMPSE is the root-mean-percent square error.

Endnotes

1. The Corn Belt states are Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin.

2. The restrictions were applied locally at sample means. Tests of the validity of the restrictions in both the short and the long run are presented in Kesavan et al. (1989).

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