CARD Livestock Model Documentation: Beef

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The U.S. beef industry has experienced continuing structural change. The size of production enterprises within the industry has expanded while the total number of producers has decreased. The percentage of fed cattle from large commercial feedlots (capacity greater than 1,000 head) has increased from less than 39 percent in 1964 to over 73 percent in 1981 (Van Arsdall and Nelson 1983). Large commercial producers have lower costs per head than smaller operations and are able to produce beef on a year-round basis, reducing seasonality within the industry. Also, through improved production practices and technological innovation, beef cow-calf producers have increased calving rates, reduced death loss, increased the rate of gain, and increased feed efficiency. These improvements are attributed to improved breeding techniques and disease control as well as to the increased use of growth-stimulating implants and feed additives (Gilliam 1985).

Regional shifts in production have also occurred. The percentage of fed cattle marketed in the Southwest and the Corn Belt/Lake States has declined, while average annual marketings in the Plains States have more than doubled from the period 1964-67 to 1977-80 (Van Arsdall and Nelson 1983).[1] However, the regional concentration of beef cow-calf operations has remained relatively constant, and only minor shifts among regions have occurred.

This report presents a quarterly econometric model of the U.S. beef sector. The model recognizes the regularities within the sector, while allowing for technological change over time. The econometric model is an abstract representation of a complex system. It is designed to aid in synthesizing data and causal relationships into a useful form. With the behavioral relationships formalized, econometric models can be used to analyze changes in policy, technology, structure, and in forecasting. For example, the models enable quantifying the impacts of new technologies such as growth hormones, examination of evidence of structural change, and assessment of advertising impacts.

The U.S. quarterly beef model is self-contained and can be linked to other subsector models of the U.S. agricultural economy. These linkages are depicted in Figure 1. The quarterly beef model is one of four econometric models of the livestock sector developed at the Center for Agricultural and Rural Development (CARD), Iowa State University. The other livestock models are also quarterly and are for the pork, chicken, and turkey sectors. They are described in greater detail in CARD Technical Reports 3 and 4 (Jensen et al. 1989 and Skold et al. 1989).

The beef 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 consumer adjustments to changes in relative retail prices. This linkage specification ignores the cross-commodity relationships at the farm level. With sufficient incentives producers could shift from beef production to other productive endeavors. However, given the concentration of production and the

capital-intensive production methods used in the beef sector, these farm-level shifts are unlikely.

The beef model also can be linked to the CARD annual feed grain model through the price of corn. The feedbacks to the annual feed grain models are 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 an effective method of transferring livestock production and price information to the feed grain sectors and soybean complex. A parsimonious set of exogenous economic factors conditions the livestock and poultry sector models in general, and the beef sector model in particular. These economic variables include the interest rate, income through food expenditures, the inflation rate, and meat packer costs.

The econometric model of the beef sector incorporates the phases in the beef production process and the primary demand categories. The supply component of the model tracks cow herd expansion and contraction decisions. Technical relationships govern the calf crop and subsequent slaughter. The supply component of the model also relies upon the regularities in the growth process for cattle as well as economic theory.

The demand component recognizes that in the short term beef supply is essentially fixed. Thus, price determination is at the retail level. The demand component also admits consumer adjustments to changes in relative prices and income that are not instantaneous. Habit formation and imperfect information flows are the reasons for the adjustment process. The inability of consumers to fully adjust implies that the static theory

does not directly apply in the short run. Demand structure restrictions from the theory are imposed in the long run, which in turn restrict consumer short-run behavior.

The organization of the paper is as follows. In the next section an overview of the model is presented. In the third section the modeling approach used is contrasted with previous econometric models of the beef economy. The fourth section contains background on the specification of the model and the estimation results. In the fifth section model behavior is evaluated, compared with models from previous studies, and validated using simulation exercises.

Model Overview

The U.S. quarterly beef model provides a representation incorporating the key behavioral relationships in the industry. In this section, a brief overview of the structure of the supply and demand components is presented. The emphasis is on general model structure and the motivation for the specification. The specification of each equation is further detailed in the discussion of results.

The sequence of beef production provides important prior information for specifying the supply structure. The model supply structure recognizes that current supply is conditioned on past breeding decisions. The size of the cow herd determines the industry's production capacity, and stages of production follow sequentially from breeding herd size decisions. These stock-flow relationships of the supply structure of the model are depicted in Figure 2.

Beef production is intrinsically linked to the size of the breeding herd. The level of supply is dependent on breeding herd investment decisions of producers. Producers expand the breeding herd by retaining heifers. This action removes the females from slaughter in the near term, and thus may temporarily reduce the beef supply before production can be expanded. Producers may also adjust the breeding herd through culling decisions. The level of cow slaughter reflects producer culling decisions.

The breeding herd determines the size of the calf crop. Calves are either raised and fed to slaughter weight or retained for breeding. The calf crop determines subsequent fed beef slaughter. Nonfed slaughter represents unfinished cattle raised to slaughter weights and is closely related to the size of previous calf crops. Cow slaughter is, in part, determined by the stock of cows available. Bull slaughter is a very small part of total slaughter. Calf slaughter and nonfed beef slaughter have continued to decline in importance.

Total slaughter, consisting of fed, nonfed, cow, and bull slaughter, multiplied by the average carcass weight for all beef animals, determines total commercial beef production. The average carcass weight is allowed to adjust to changing market conditions. Total domestic beef supply includes on-farm slaughter plus total commercial production. Domestic disappearance is the difference between total commercial supply and changes in other use categories, which include imports and exports, cold-storage stocks, and military use. Cold-storage stocks are

represented by a behavioral equation; the other use categories are considered exogenous in the model.

As in most livestock models, the lag structure in the supply block is governed by the biological sequence in the production process. The biological production sequence provides additional information for the specification of supply. Biological relationships inherent in beef production are incorporated in the behavioral equations. These restrictions provide prior constraints on the supply response, which reflect the natural biological processes in production. Thus, the supply response is governed by the time lags in the breeding, gestation, birth, and finishing. Of course, supply response is also dependent on producer decisions. Input and output prices are included in the supply structure to reflect producer profit incentives. Quarterly dummy variables account for seasonality.

The method for incorporating biological restrictions in the supply functions was first developed by Johnson and MacAulay (1982) in a quarterly beef model. Historical biological relationships were used to obtain restrictions on the supply parameters. The biological restrictions provide a priori information for the estimation of the stock-flow relationships governing the phases of beef production. This approach has been used subsequently for beef (Okyere 1982; Okyere and Johnson 1987), poultry (Chavas and Johnson 1982; Jensen et al. 1989), pork (Blanton 1983; Oleson 1987; Skold et al. 1989), and dairy (Chavas and Klemme 1986). In the CARD beef model biological restrictions are imposed in the equations

determining the calf crop, fed slaughter, nonfed slaughter, cattle placements, and fed marketings.

The biological restrictions can also be imposed in the functional form. Chavas and Klemme (1986) applied this method in an analysis of investment behavior for the U.S. dairy industry. Similar functional forms are used in the equations that represent heifers added to the breeding herd and cow slaughter for the CARD beef model. With this method the biological constraints are fulfilled, but producers are allowed more behavioral discretion.

The demand structure, which provides a representation of consumption behavior, presumes that consumers cannot instantaneously adjust to shifts in relative prices and income. Persistence in consumption patterns implies the axioms of consumer behavior may be violated in the short run. That is, 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. Thus, the precepts of consumer behavior are imposed on the long-run demand, and they constrain consumption behavior in the short run.

Price is determined at the retail level. Supply is essentially perfectly inelastic in the current period, and thus the level of price is dependent on demand. The price determination process of the beef model is illustrated in Figure 3. The retail price is dependent on per capita beef consumption, prices of competing meats and food products, and food expenditures. The retail price is linked to the farm price through an

estimated margin. The margin is influenced by both demand and supply shifts, and by changes in marketing costs.

Review of Previous Econometric Models

Many econometric models for livestock have specifications tied to relatively simple supply structures that use distributed lags of input and output prices. In part, the lags reflect assumed adjustment costs in the production process. Seasonality, an important feature of the livestock industry, is handled mainly with dummy variables. The popularity of this basic supply structure reflects regularities in the livestock production growth process, ease of implementation and estimation, and the relative success experienced in capturing producer behavior. Demand specifications are predominantly simple static linear structures that do not presuppose adherence to the static consumer theory.

Identifying the underlying reasons for the cyclical nature of beef production and prices provided the initial impetus for modeling the beef economy. Explanations for the cyclical nature of beef production were initially reflected in two schools of thought: a self-generating mechanism using the so-called Cobweb theorem, or induced by outside influences such as changes in meat demand, weather, and available feed supplies (Breimyer 1955). 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 sequence inherent in livestock production as one of the underlying mechanisms generating cycles (Harlow 1962).

In econometric models of the beef sector, supply is determined by the number of cows calving, which is dependent on profitability expectations. The size of the calf crop determines total beef slaughter, which in turn determines beef production. This general structure continued to be replicated in later econometric models (e.g., Stillman 1985).

Often this simple supply structure has been augmented by including intermediate steps between calving and subsequent slaughter. Equations that represent the calf crop, the level of cattle on feed, and heifers added to the breeding herd are examples. The lag structures in these intermediate steps remain tied to the biological timetable for beef production and thus include a distributed lag form. Examples of extended supply structures include Maki et al. (1962), Arzac and Wilkinson (1979), and Freebairn and Rausser (1975).

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

Estimation Results

The U.S. quarterly beef industry model contains 14 behavioral equations and 12 identities. These expressions provide behavioral representations of the major components of the industry supply and demand structure. The supply structure disaggregates the phases in the production process, and it includes behavioral relationships for heifers added to the breeding herd, cow slaughter, the calf crop, 13-state cattle placements and fed marketings, fed slaughter, and nonfed slaughter. Cow herd inventory is derived through an identity. Domestic beef production is the sum of the fed, nonfed, cow, and bull slaughter multiplied by an average carcass weight of all slaughtered animals.

The average carcass weight adjusts to movements in the slaughter steer price and the level of total slaughter. Total commercial beef supply includes domestic production plus on-farm slaughter. The demand component reflects retail demand and cold-storage stocks equations. The retail price is derived from the retail demand equation. A margin equation defines the retail-farm price spread. 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. The estimation methods employed were nonlinear least squares (NLS), restricted least squares (RLS), generalized least squares (GLS), and ordinary least squares (OLS). The retail demand equation was estimated within a demand system that contains 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 for each equation. The description of the results and underlying specifications begins with the estimation results of 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. The definitions of the variables and details on data sources and the construction of the variable are provided in Table 4.

Supply Component

Beef industry production capacity is determined by the size of the breeding herd. The breeding herd reflects past investment decisions of producers. Producers can expand the breeding herd, and thus increase future production capacity by retaining heifers. Heifers, which are female cows that have not yet calved, are available for breeding at 14 to 15 months of age. Since in the short term the number of heifers available for replacement purposes is limited, production must decline in aggregate before the results of retaining additional heifers expand supply. This dual role of heifers in the beef production process has direct implications on the cyclical nature of production.

In the heifers added to the breeding herd equation (1), a logistic functional form is used so that the number of heifers added is bounded from above by the total number of calves in the calf crop lagged four through seven quarters, CALF4. This restriction on heifer retention is in the spirit of the biological restrictions developed by Johnson and MacAulay (1982) and applied by others. This functional form introduces a biological restriction on the number of calves that can be retained, but allows for more producer discretion in their breeding herd expansion and contraction decisions. With this functional form the conditioning variables and input and output prices must increase proportionally more in order to induce increased levels of heifer retentions. This specification is similar to that used by Chavas and Klemme (1986) for the dairy industry.

The breeding herd management decisions of producers are based on their perceptions of profitability of their cow-calf operations. The slaughter steer price, PSS4, is included to account for changes in the "output" price. Cow-calf operators face a derived demand, and thus their profitability is closely tied to feedlots' demand for feeder cattle. The results suggest that producers increase retentions when the average of the lagged three-through-six-quarters price of slaughter steers increases.

The "input" prices that condition the retention decisions are the corn price, PCO4, and the real interest rate, RIFCL. The corn price provides an indication of the expected profitability of cattle feeding. The real interest rate is used as a proxy for investment cost. Both variables are included as the average of the lagged three through six

quarters, and they are negatively related to retentions. The lag structures in all conditioning variables in the heifers added equation reflect the necessary gestation and grow-out phase before heifers can be added to the breeding herd. Quarterly dummy variables capture the seasonality of the process. The logarithm of the time trend, LT65, captures changes in heifer retentions over time.

The other component determining the breeding herd is the outflow of breeding herd stock. This is represented by cow slaughter (2), which has the same logistic functional form as the heifers added to the breeding herd equation (1). However, cow slaughter is bounded from above by the total cow herd, which provides a biological restriction. Similar to the heifers added equation, input and output prices must decrease proportionally more to attain higher levels of cow slaughter.

Cow slaughter is dependent on profitability expectations of producers. The same set of conditioning variables is used, but the time frame is shifted forward. The average of slaughter steer prices, current through lagged three quarters, provides a measure of changes in the "output" price. The corn price and the real interest rate are included using this same lag structure and provide proxies for changes in the cost structure. The logarithm of the time trend reflects intertemporal changes in the breeding herd culling rates. Again, quarterly dummy variables reflect the seasonal variation of cow slaughter.

The slaughter steer price has a negative relationship with the level of cow slaughter, indicating that beef cow-calf producers will reduce cow slaughter in response to higher slaughter steer prices. Similarly,

increases in the price of corn increase the rate of cow slaughter. The real interest rate has an opposite effect on cow slaughter, compared to that on heifers added. Thus, an increase in the real interest rate will increase cow slaughter.

The cow herd (3) is determined by an identity and is the sum of the lagged cow herd and the lagged heifers added, less the lagged cow slaughter. The lagged cow herd is multiplied by 0.995 to account for an assumed 2 percent annual death loss. The identity equates changes in the stock of the breeding herd with the net of additions less slaughter, or flows into the breeding stock:

$$COWHERD_t - 0.995 * COWHERD_{t-1} = HEIFERS_{t-1} - CSLT_{t-1}.$$

The beef cow herd (4) is simply solved by an identity that subtracts the number of dairy cows, DAIRYCOW, from the cow herd.

The calf crop (5) is specified as a technical relationship and incorporates the biological restrictions first advanced by Johnson and MacAulay (1982). Even though there have been technological advances leading to improved calving rates and reduced death loss, there is a reasonably constant relationship between the size of the cow herd and the calf crop. Thus, the coefficients in the calf crop equation are set equal to the quarterly sample means of the ratio, CALFCROP/COWHERD (see Table 2).

Identities are used to derive the three categories of the calves in the model. The calf crop--light weights (6), calf crop--medium weights

(7), and calf crop--heavier weights (8) contain the sum of the lagged two through five calf crops, lagged four through seven calf crops, and lagged five through eight calf crops, respectively.

The cattle placed on feed--13 states (9) is a function of the calf crop lagged two through five quarters, CALF2. Biological ratios are used as a priori information in the estimation of cattle placements. The ratio of CATPL13/CALF2 has demonstrated an upward trend since 1972 in each quarter. Thus, the ratio is detrended with DUM72 and T65 * DUM72, and the resulting estimates are restricted in the placement equation.

Also included in the placement equations are the lagged slaughter steer price, PSS4, and the lagged price of corn, PCO4. The slaughter steer price has a positive effect on placements because cattle feeders attempt to fill the feedlots as "output" price increases. An increase in the corn price reduces placements, indicating the producer response to an increase in the cost of feeding cattle to slaughter weights. The level of cattle on feed--13 states (10) is determined by an identity similar to the one used for the cow herd. Changes in the stock, or number of cattle placed on feed, is equal to the difference between the outflows (fed marketings) and inflows (placements).

The outflows from the feedlots, or the level of cattle fed marketings--13 states (11), is determined by the level of cattle on feed and the number of placements in the same quarter. The current placements variable is included to account for the placement of heavier weight yearlings. The coefficients on the sum of cattle on feed and placements, CATNF13 + CATPL13, originate from the underlying biological ratios. As

before, the coefficients are restricted to the quarterly sample means of the corresponding biological ratio, CATFM13/(CATNF13 + CATPL13) (see Table 2).

The economic variables included in the fed marketings equation are the slaughter steer price, PSS4, deflated by the price of corn, PCO4, and the real interest rate on feeder cattle loans, RIFCL. The slaughter steer price is negatively related to fed marketings. Feedlot operators feed their cattle to heavier weights as the slaughter steer price increases, and thus they increase the time on feed. Similarly, the corn price has a positive effect on fed marketings, since costs of feeding cattle to heavier weights are higher as feed costs rise. Producers may also have incentives to increase the stock of nonfed cattle destined for slaughter. The real interest rate on feeder cattle loans has a positive effect on fed marketings resulting in earlier marketings at reduced weights. Increased interest costs of holding cattle on feed induce a greater level of marketings.

Fed cattle slaughter (12) is determined by the level of fed marketings. The coefficients on cattle fed marketings--13 states--were restricted according to information from the ratio of FEDSLT/CATFM13. The biological ratio, FEDSLT/CATFM13, was regressed on DUM74 and T65 * DUM74 since it exhibits a downward trend in the early years of the sample. The coefficients from this detrending exercise are restricted in the fed slaughter equation.

Nonfed cattle slaughter (13) is determined by the calf crop lagged five through eight quarters, CALF5. Biological ratios provide prior

information on the relationship between the number of heavier calves and the level of nonfed slaughter. The ratio of NFSLT/CALF5 indicates a downward trend through 1974. Thus, the ratio was detrended with DUM73 and T65 * DUM73, and, as before, the resulting coefficients are restricted in the nonfed slaughter equation.

The 600- to 700-pound feeder steer price, PFCL4, and the corn price, PCO4, are included as conditioning variables and calculated as the average of the lagged one through four quarters. The feeder cattle price has a negative effect on nonfed slaughter, presumably because as feeder calf prices increase, calves and yearlings are sold as feeder cattle instead of being range fattened. The corn price has the opposite effect on nonfed slaughter, since increases in the corn price reduce the demand for feeder cattle, and thus increase the stock of nonfed cattle destined for slaughter.

The biological relationships used in the heifers added, cow slaughter, calf crop, cattle placements, fed marketings, fed slaughter, and nonfed slaughter equations are incorporated in the ratios previously discussed. Given the biological nature of beef production, the quarterly means of these ratios provide a priori information in the estimation of the supply components of the model. However, only in the calf crop, cattle placements, fed marketings, fed slaughter, and nonfed slaughter equations are these quarterly means directly used. The biological relationships intertwined in these ratios are assumed to be relatively constant and are used to estimate the parameters in the

biological portion of the supply component of the model. Quarterly means and standard deviations for the ratios are presented in Table 2.

The first ratio, CALFCROP/COWHERD, is the ratio of the calf crop to the current cow herd. The current calf crop is constrained by the available breeding stock, or the current cow herd. Quarterly averages of this ratio provide information on the calving rate of the total available breeding stock. Quarterly means for the ratio illustrate the seasonality in calving.

The ratio of the cattle placed on feed for the 13 states to the lagged calf crop two through five quarters, CATPL13/CALF2, depicts the relationship between the available feeder cattle stock and their subsequent placement into feedlots. The available feeder cattle stock, CALF2, is the sum of the calf crop lagged two through five quarters, and it represents the calves and yearlings ready to be placed on feed. Thus, the ratio CATPL13/CALF2 relates available feeder supply with actual placements. The ratio indicates that, on average, 11 to 16 percent of the available stock of calves are placed on feed each quarter.

The next ratio, CATFM13/(CATNF13 + CATPL13), relates the number of cattle fed marketings in the 13-state region to the number of cattle placed on feed in the same region for the current quarter. The sum of the cattle on feed and the cattle placed on feed approximates the number of cattle ready for slaughter. The quarterly means of the ratio CATFM13/(CATNF13 + CATPL13) represent the proportion of available cattle on feed ready for market to the number of fed cattle marketed. The ratio of fed cattle slaughter to cattle fed marketings, FEDSLT/CATFM13, is an

extension of the ratio detailed previously. The number of cattle marketed in the 13-state region is used as a proxy for the total available cattle ready for slaughter. Similarly, the ratio NFSLT/CALF5 represents the proportion of heavier calves fattened on the range and ready for slaughter.

As expected, the quarterly means for the ratios are not constant across quarters. Plots of the above ratios against time, by quarter, indicate that changes have occurred in some of the ratios over time. For example, the ratio FEDSLT/CATFM13 demonstrates a downward trend at the beginning of the sample, with a leveling after 1974. This may be attributed to increased cattle feeding in states outside the 13-state region. Thus, to accurately reflect these changes in seasonality and structural changes through time, the ratios were detrended by quarter. The trends in the biological ratios were accounted for by regressing a zero-one dummy variable and a time trend variable on the biological ratios, by quarter. The plots of the ratios, by quarter, provided indications of threshold points at which shifts in the ratios occurred. The general form of the regression equation was

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

where i = 1, 2, 3, 4 is the period; R_i is the biological ratio; t is the time trend t = 1.00, 1.25, ...; DV_i is one if less than the threshold point and is zero otherwise; a, b, c are the 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. This specification of the regression equation is used to detrend several of the ratios. The regression results are imposed in the structure of the supply components. The parameter estimates are fixed a priori in the various structural equations of the supply system.

The average carcass weight commercial production (14) is a function of total slaughter, FEDSLT + NFSLT + CSLT + BSLT, and the slaughter steer price, PSS4. The negative relationship between the level of total cattle slaughtered and the average carcass weight reflects the fact that given the fixed supply of cattle at the heavier weight range, increases in numbers of cattle slaughtered must be obtained from the stock of lighter-weight cattle. The slaughter steer price has a positive effect on the average carcass weight, since at higher prices cattle feeders are induced to feed cattle to heavier weights.

Total commercial beef production (15) is determined by an identity that multiplies the average carcass weight by the level of total slaughter. Total beef production (16) is simply total commercial beef production plus on-farm production, FPD.

Demand Component

Price determination of the model occurs at the retail level. As Fox (1953) observed, livestock production is essentially fixed in the short run, and hence the determination of 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 that is determined with a behavioral equation is closing cold-storage stocks. Domestic disappearance, which determines per capita beef consumption, is derived from the market closing identity. The estimation results of the demand components are provided in Table 3.

Prevalent forms of demand functions used in livestock sector models are static and of ad hoc nature, and they do not follow the precepts of consumer behavior. In part this reflects the rejection of the static theory 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, implied by the static approach, of instantaneous consumer adjustment to changes in relative prices and income, as well as to aggregation problems.

Consumers often react with delay to changes in relative prices and income. Habit formation in consumption may lead to delayed responses, and thus protract the adjustment process (Pollack and Wales 1980; Blanciforti et al. 1986; Heien 1982; Johnson et al. 1984). This underlying inertia in consumption implies that consumer behavior dynamics should be explicitly introduced into the specification of the demand component.

The retail demand component used in the model incorporates persistence in consumption. The model begins with specification of a general set of stochastic difference equations. From this, a final form is obtained and then error correction methods are applied to estimate the equations (Anderson and Blundell 1983). A log-linear model is used, in

spite of the obvious theoretical limitations (LaFrance 1986), mainly for computational and expositional convenience.

The general specification, developed from the final form of the set of stochastic difference equations, allows for 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. Short-run behavior is captured in the β_j parameters, and the speed of the adjustment process is governed by $\alpha - 1$. The long-run parameters are ϵ_{ij}. The specification utilizes a fourth-order lag structure because of the periodicity of the data. The fourth-order difference operator is Δ_4.

The terms within the brackets continually move consumption levels to their 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. In essence, this is the error correction mechanism by which consumers adjust consumption levels toward the 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).

This general structure was used to estimate the retail beef demand (17). Retail beef demand was estimated within a system of demand equations that included representations for pork and chicken, the primary competing meat products. Thus, the retail prices of pork and chicken enter as conditioning variables in the beef demand specification. Other conditioning variables included were per capita food expenditures and the consumer price index of food, a proxy for all 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 static consumer theory 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 for the short-run parameters. In the long run consumers have the ability to fully discern relative price and income shifts, and thus they adhere to the precepts of consumer theory. Hence, the homogeneity and symmetry restrictions were imposed on the 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 demand results, presented in Table 3, have the correct signs, except for the coefficients on the retail price of chicken and the derived coefficients on the price index of foods. The negative cross-price

elasticities for chicken correspond to previous results (Wohlgenant and Hahn 1982). The negative elasticities with the price index of foods suggest a complementary relationship with beef consumption. The estimates also suggest, as expected, that cross-price effects increase as consumers have time to adjust to relative price changes. This behavior holds true for the expenditure elasticity as well. However, the own-price elasticity declines over time.

The adjustment coefficient that governs the movement to long-run equilibrium was 0.33. This coefficient is greater than similar coefficients in the pork and chicken demand equations and indicates that beef demonstrated the least amount of persistence, while pork and chicken consumption had higher levels of persistence in consumption.

The real retail-farm margin equation (18) links the retail price with the slaughter steer price (Table 3). The margin specification is as that derived by Wohlgenant and Mullen (1987) and allows for the influences of supply and demand shifts as well as marketing cost changes. The explanatory variables include the retail price deflated by the consumer price index, CPI. This influence of the retail price is allowed to vary among the quarters. Also included as an explanatory variable is the real per capita value of beef production, RPBF4/CPI * TOTBSP/POPN4. This variable has a positive effect on the retail-farm margin. Thus, when supply processed increases, or when the retail price increases, the margin between retail price and farm price widens.

The margin is also a function of an index of marketing costs and the lagged real retail-farm margin. The marketing cost index includes both

meat packers' wage rate and a measure of fuel and utilities costs. Hayenga et al. (1985, 51) note that "labor costs comprise nearly one-half of meat packers' operating costs." The fuel and utilities index incorporates changes in general overhead costs. As expected, the marketing cost index has a positive effect on the retail-farm margin. The lagged real retail-farm margin also has a positive effect.

The price of choice slaughter steers (19) is derived from an identity, the retail price less the margin (Table 3). There are three price equations that depend primarily on the price of slaughter steers. These three equations are estimated using an autoregressive correction term. The price of commercial utility cows (20) includes variables for the price of 400- to 500-pound feeder steers, PFC4, the price of corn, and a dummy variable for the Nixon price freeze of 1973, FREEZE. The utility cow price is positively related to the price of feeder steers and the price of corn. The price freeze has a negative effect on price. Quarterly dummy variables are included for seasonality in prices.

The price of feeder steers, 400-500 pounds (21) is estimated as a function of the present and lagged 600- to 700-pound feeder steer price, PFCL4, the price of corn, and the Nixon price freeze dummy variable. The 600- to 700-pound feeder steer price is positively correlated with the 400- to 500-pound feeder steer price, but the price of corn has a negative effect. The coefficient on the price freeze variable is negative. The equation estimating the price of feeder steers, 600-700 pounds (22) is similar to the equation for lighter weight steers. The present and lagged slaughter steer prices have a positive impact, and the corn price has a

negative impact. Quarterly dummy variables are included in both of the feeder steer price equations.

The other demand component is closing cold-storage stocks (23). The level of cold-storage stocks is a function of the retail price of beef, total beef production, beef imports, and the level of beginning stocks. The retail price of beef has a negative effect on ending stocks because as prices increase, packers are less willing to hold excessive stocks. Total supply, imports, 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 (24) are simply ending stocks from the previous period.

The market clearing identity equates available beef supply and demand. From this identity total beef domestic disappearance (25) is obtained. Exogenous supply and demand components included in the identity are exports, EXP; imports, IMP; shipments, SHIP; and military use, MILIT. Domestic disappearance is divided by the U.S. population and multiplied by the carcass-retail weight conversion ratio to obtain per capita beef consumption (26).

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

Validation and Evaluation

Validation exercises help to establish how well the behavior of the model corroborates the outputs of the system modeled. The estimated equations provide approximations of the supply and demand in the beef

sector. Before these approximations can be used to evaluate the reaction of the beef sector to policy shifts and technology advances, the integrity of the systems must be checked.

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 beef sector. The elasticities are derived with nonlinear simulation techniques, following 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. RMPSE is a measure of the absolute deviation of the predicted values from the historical values 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 for the period 1970-1986.

The historical simulation statistics indicate the model provides an adequate representation of the beef sector behavior. The simulation statistics of the nonfed cattle slaughter and the live cattle prices are larger than desired. Nonfed slaughter is a difficult relationship to specify. This is due, in part, to the large variety of factors that may influence nonfed cattle destined for slaughter. Individual producer yearly grain and forage production, availability of grazing land, etc., as well as the profitability of finishing cattle to market weights, affect

the level of nonfed slaughter. The slaughter steer price is determined by estimated retail price and retail-farm margin. Errors from these two variables are compounded in the estimation of live cattle prices within the model.

With linear models the dynamic properties can be examined through the reduced form equations of the estimated model. Mean paths, multipliers, and elasticities can be obtained directly from the reduced form equations. However, with nonlinear models such as the beef model, the reduced form expressions cannot be analytically derived. Fair (1980) illustrates the use of simulation methods to derive the dynamic behavior of nonlinear models. In deriving the beef model dynamics, these simulation techniques were applied with two simplifying assumptions. First, all stochastic terms were set to zero. Second, the parameters were assumed to be known with certainty.

Briefly, the steps used to derive the approximate dynamic multipliers are as follows. First, a baseline solution was obtained by setting all exogenous variables to predetermined values (1984-1986 means). The model was simulated until the endogenous variables reached constant levels. This baseline of steady-state solutions was then used for comparison to results or simulations in which selected exogenous variables were perturbed. Feed costs, interest rates, and retail pork and chicken prices were increased by a sustained 10 percent from their 1984-1986 mean values for the exercises (Tables 6 through 9). The model was simulated for each of these four exogenous shocks and was allowed to converge on a new steady-state solution. The new solution typically was obtained after 40

quarters (denoted period in the tables). Percentage changes from the baseline for the feed cost, interest rate, retail pork price, and retail chicken price simulations are provided for selected endogenous variables.

The estimated responses of the selected endogenous variables indicate that supply is inelastic in the short run, but that it becomes increasingly elastic as the effects of heifer additions and changes in the level of cow slaughter are reflected. The biological constraints on production prohibit instantaneous increases in supply without an underlying buildup of the breeding herd. Thus, the supply response does not become apparent 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 a 4.32 percent increase in the farm price (PSS4), and a 2.30 percent reduction in supply (TOTBSP) after the model equilibrates. The sustained 10 percent increase in the retail pork price (RPPK) leads to a 5.40 percent increase in supply (TOTBSP), but no change in the farm price (PSS4). Similar responses are found in the other tables (Tables 7 through 9). This indicates that the supply response of producers nearly eliminates the change in the farm price. Of course, these multipliers were simulated holding all other variables constant; thus, dynamic cross-commodity effects are ignored.

Comparisons of supply elasticities for selected beef sector models are provided in Table 10. The reported supply elasticities for the CARD quarterly beef model are constructed as a response to a one-year increase in the slaughter steer price. In simulating the elasticities, only the supply components of the model were used, and all exogenous variables

(e.g., corn price, interest rates) were set at their 1984-1986 means. Within four years the model converges to a long-run beef supply elasticity of 0.16. The short-run elasticities are the average response during the first year of the slaughter steer price increase. The short-run beef supply elasticity is -0.03, and the short-run elasticities of fed and nonfed slaughter are 0.13 and -0.53, respectively.

Differences among the elasticities from different studies reported in Table 10 exist for many reasons. The period of study is one reason. Differences in the method of calculating the elasticity may also affect their values. Analytical approaches directly from estimated parameters may provide a different measure of supply response compared with the simulation approach used in this study. Nevertheless, the estimated supply elasticities for the CARD model are similar to those obtained in previous works.

The demand 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 fully adjust to relative price and income changes as time passes. The long-run, own-price beef elasticity declines relative to the short-run estimate. The beef demand elasticities have the expected signs except for the cross-price elasticity with chicken. They are negative but increase to a near-positive value in the long run. Table 12 gives demand elasticities from selected other beef demand studies. The demand elasticities in the CARD model are in line with previous results.

An ex post forecast was made for the four quarters of 1987. It was necessary to raise exogenous feed costs for 1987 in order to complete the forecast. Feed costs were raised to a level approximating the steer-corn price ratio of the sample period. The actual steer-corn price ratio during 1987 was nearly twice the historical average; thus, it led to a predicted extensive industry expansion within the model if no adjustment was made. The RMPSEs for the forecast are provided for selected endogenous variables in Table 13. The results are as expected, although the model overestimates live cattle prices, even with the adjustment in feed prices. The model does not predict heifer additions or cow slaughter as accurately as would be desirable.

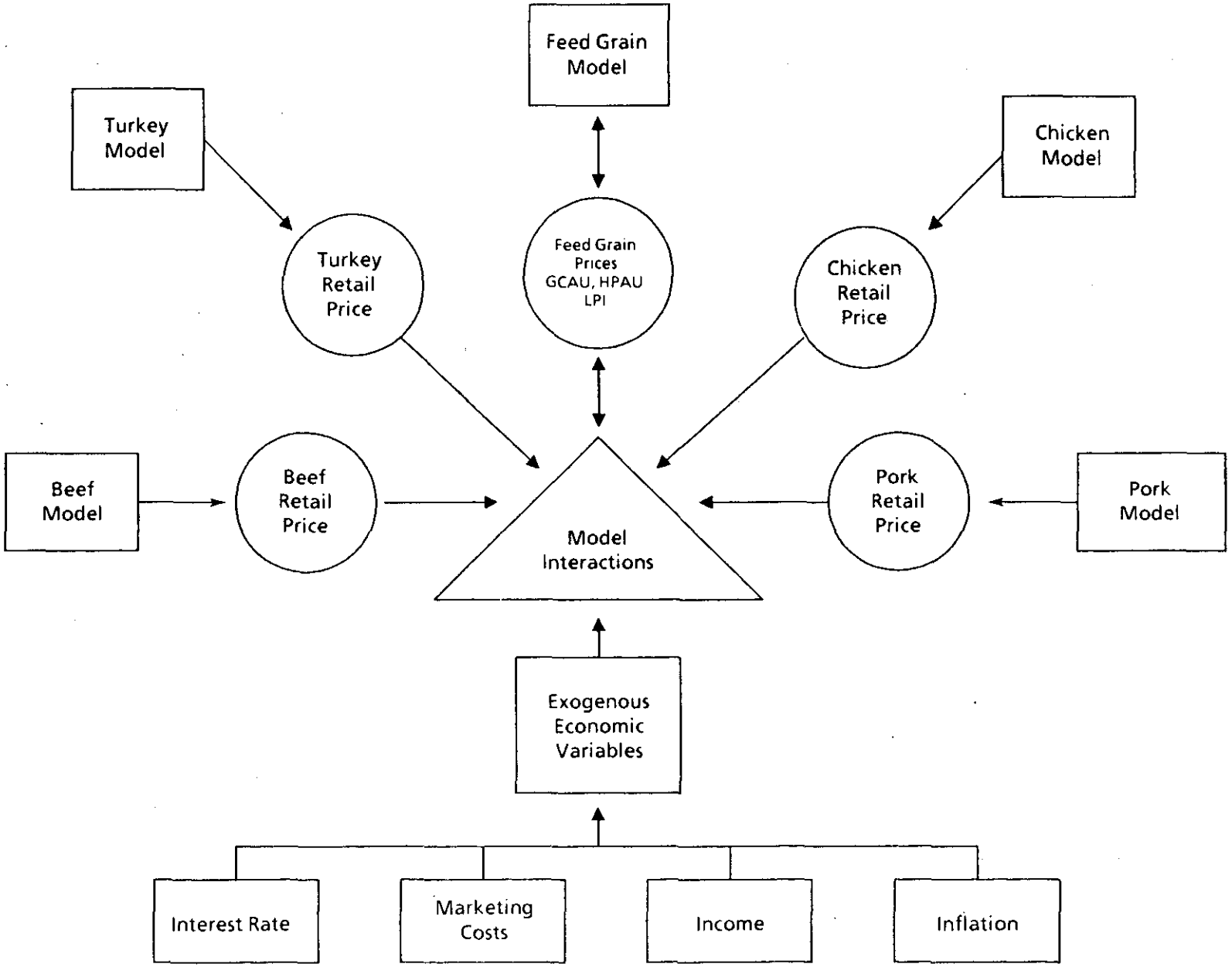

Figure 1. Livestock sector model linkages.

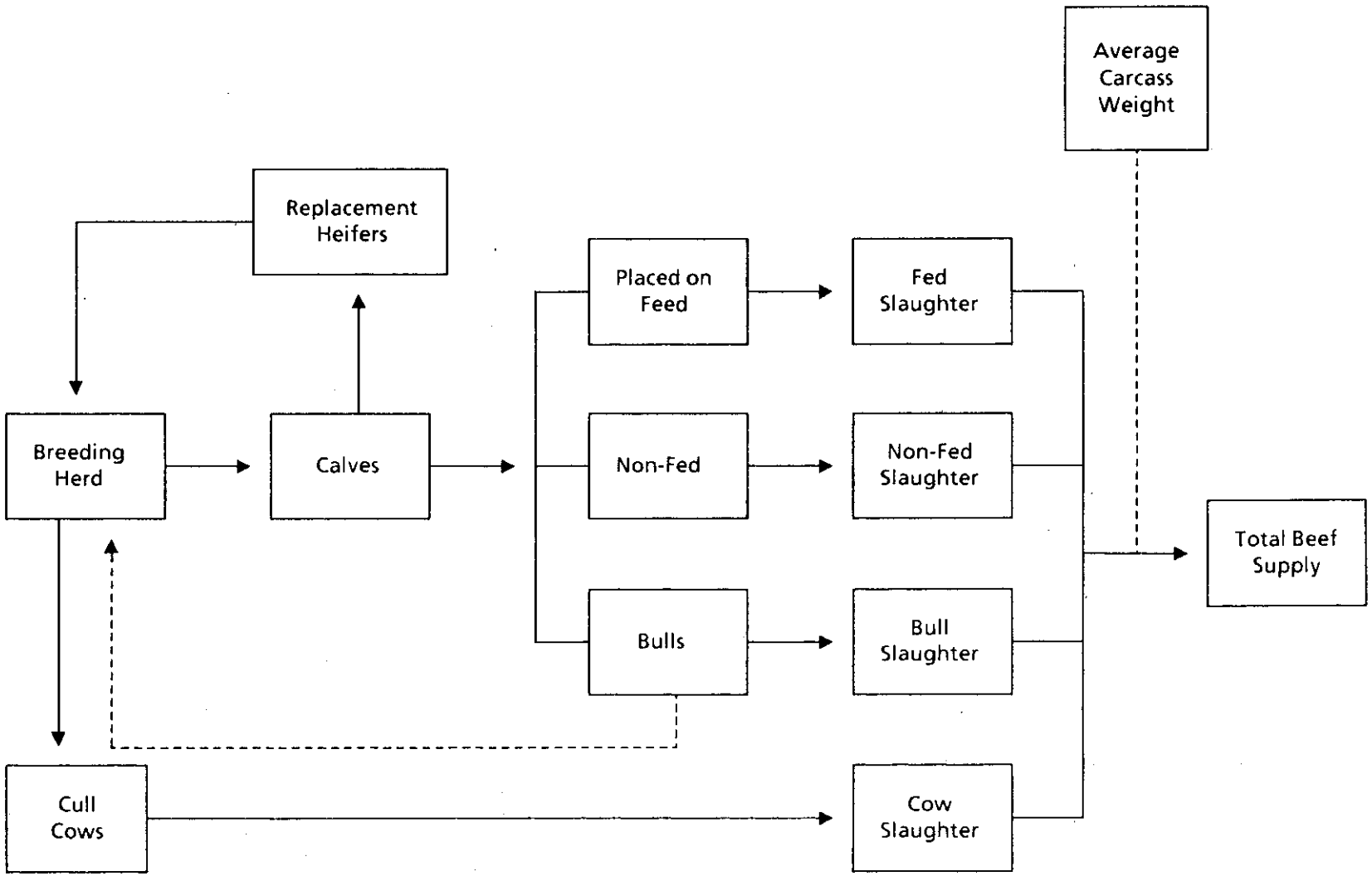

Figure 2. Supply components of the U.S. quarterly beef model.

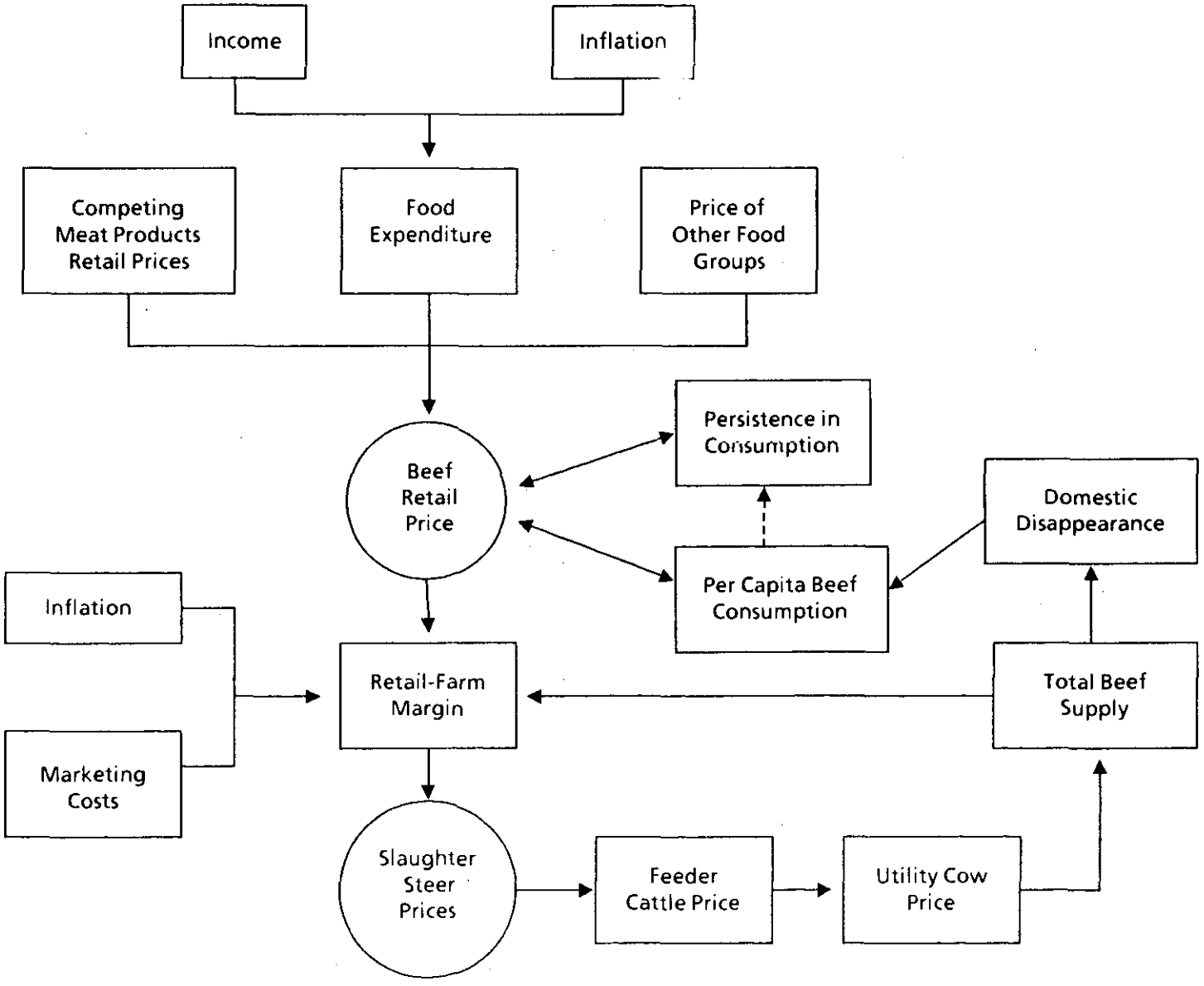

Figure 3. Price determination of the U.S. quarterly beef model.

Table 1. Estimates of beef supply components

(1) Heifers added to the breeding herd (NLS)

$$
\begin{aligned}
HEIFERS_t = CALF4_t/\{1 + EXP[&\underset{(17.44)^{a}}{2.77893} + \underset{(1.05)}{0.4689}\ D2 \\
&+ \underset{(5.66)}{0.28535}\ D3 + \underset{(0.03)}{0.13915}\ D4 \\
&- \underset{\substack{(-2.03)\\ [0.27]^{b}}}{0.005919}(PSS4_{t-3} + PSS4_{t-4} + PSS4_{t-5} + PSS4_{t-6})/4 \\
&+ \underset{\substack{(1.70)\\ [-0.16]}}{0.07768}(PCO4_{t-3} + PCO4_{t-4} + PCO4_{t-5} + PCO4_{t-6})/4 \\
&+ \underset{\substack{(2.60)\\ [-0.05]}}{0.01287}(RIFCL_{t-3} + RIFCL_{t-4} + RIFCL_{t-5} + RIFCL_{t-6})/4 \\
&+ \underset{(0.64)}{0.07873}\ LT65]\}
\end{aligned}
$$

$S/M = 0.139^{c}$

(2) Cow slaughter (NLS)

$$
\begin{aligned}
CSLT_t = COWHERD_t/\{1 + EXP[&\underset{(26.65)}{3.80187} + \underset{(1.51)}{0.07629}\ D2 \\
&- \underset{(-0.29)}{0.01397}\ D3 + \underset{(-3.68)}{-0.1674}\ D4 \\
&+ \underset{\substack{(7.29)\\ [-0.97]}}{0.02128}(PSS4_t + PSS4_{t-1} + PSS4_{t-2} + PSS4_{t-3})/4 \\
&- \underset{\substack{(-5.69)\\ [0.48]}}{0.24128}(PCO4_t + PCO4_{t-1} + PCO4_{t-2} + PCO4_{t-3})/4 \\
&- \underset{\substack{(-2.25)\\ [0.05]}}{0.01212}(RIFCL_t + RIFCL_{t-1} + RIFCL_{t-2} + RIFCL_{t-3})/4 \\
&- \underset{(-3.73)}{0.39068}\ LT65]\}
\end{aligned}
$$

$S/M = 0.142$

Table 1. Estimates of beef supply components (continued)

(3) Cow herd

$$COWHERD_t = 0.995\ COWHERD_{t-1} + HEIFERS_{t-1} - CSLT_{t-1}$$

(4) Beef cow herd

$$COWHERD_t = COWHERD_t - DAIRYCOW_t$$

(5) Calf crop (RLS)

$$CALFCROP_t = 0.3317\ COWHERD_t * D1 + 0.3168\ COWHERD_t * D2 + 0.0818\ COWHERD_t * D3 + 0.1744\ COWHERD_t * D4$$

$$S/M = 0.038$$

(6) Calf crop--light weights

$$CALF2_t = CALFCROP_{t-2} + CALFCROP_{t-3} + CALFCROP_{t-4} + CALFCROP_{t-5}$$

(7) Calf crop--medium weights

$$CALF4_t = CALFCROP_{t-4} + CALFCROP_{t-5} + CALFCROP_{t-6} + CALFCROP_{t-7}$$

(8) Calf crop--heavier weights

$$CALF5_t = CALFCROP_{t-5} + CALFCROP_{t-6} + CALFCROP_{t-7} + CALFCROP_{t-8}$$

Table 1. Estimates of beef supply components (continued)

(9) Cattle placed on feed--13 states (RLS)

$$
\begin{aligned}
CATPL13_t = {} & (0.1129 + 0.003736\ T65 * DUM72 - 0.02864\ DUM72) \\
& * CALF2_t * D1 \\
& + (0.1184 + 0.007769\ T65 * DUM72 - 0.05981\ DUM72) \\
& * CALF2_t * D2 \\
& + (0.1209 + 0.005734\ T65 * DUM72 - 0.04244\ DUM72) \\
& * CALF2_t * D3 \\
& + (0.1555 + 0.004502\ T65 * DUM72 - 0.02934\ DUM72) \\
& * CALF2_t * D4 \\
& + \underset{\substack{(5.33) \\ [0.26]}}{0.03133\ PSS4_{t-1}} - \underset{\substack{(-5.12) \\ [-0.25]}}{0.6676\ PCO4_{t-1}}
\end{aligned}
$$

S/M = 0.056

(10) Cattle on feed--13 states

$$CATNF13_t = CATNF13_{t-1} + CATPL13_{t-1} - CATFM13_{t-1}$$

(11) Cattle fed marketings--13 states (RLS)

$$
\begin{aligned}
CATFM13_t = {} & 0.3689(CATNF13 + CATPL13)_t * D1 \\
& + 0.3668(CATNF13 + CATPL13)_t * D2 \\
& + 0.3788(CATNF13 + CATPL13)_t * D3 \\
& + 0.3381(CATNF13 + CATPL13)_t * D4 \\
& - \underset{\substack{(-3.38) \\ [-0.02]}}{0.005253(PSS4/PCO4)_t} + \underset{\substack{(3.95) \\ [0.02]}}{0.02368 * RIFCL_t}
\end{aligned}
$$

S/M = 0.011

Table 1. Estimates of beef supply components (continued)

(12) Fed cattle slaughter (RLS)

$$FEDSLT_t = (1.3043 - 0.01450\ T65 * DUM74 + 0.1450\ DUM74)\ CATFM13_t * D1$$
$$+ (1.1466 - 0.01263\ T65 * DUM74 + 0.1334\ DUM74)\ CATFM13_t * D2$$
$$+ (1.1488 - 0.009914\ T65 * DUM74 + 0.1073\ DUM74)\ CATFM13_t * D3$$
$$+ (1.1301 - 0.01863\ T65 * DUM74 + 0.1733\ DUM74)\ CATFM13_t * D4$$

S/M = 0.078

(13) Nonfed cattle slaughter (RLS)

$$NFSLT_t = (0.01357 - 0.00558\ T65 * DUM73 + 0.040611\ DUM73)\ CALF5_t * D1$$
$$+ (0.01841 - 0.00555\ T65 * DUM73 + 0.037530\ DUM73)\ CALF5_t * D2$$
$$+ (0.021039 - 0.007136\ T65 * DUM73 + 0.048172\ DUM73)\ CALF5_t * D3$$
$$+ (0.022589 - 0.006017\ T65 * DUM73 + 0.041067\ DUM73)\ CALF5_t * D4$$
$$- \underset{\substack{(-9.55)\\ [-0.89]}}{0.018823}(PFCL4_{t-1} + PFCL4_{t-2} + PFCL4_{t-3} + PFCL4_{t-4})/4$$
$$+ \underset{\substack{(9.20)\\ [0.98]}}{0.428721}(PCO4_{t-1} + PCO4_{t-2} + PCO4_{t-3} + PCO4_{t-4})/4$$

S/M = 0.067

(14) Average carcass weight commercial production (OLS)

$$AVECW_t = \underset{(30.2)}{717.7121}\ D1 + \underset{(30.1)}{715.4490}\ D2 + \underset{(29.1)}{714.0620}\ D3 + \underset{(29.1)}{718.8357}\ D4$$
$$+ \underset{\substack{(5.55)\\ [0.05]}}{0.6011}\ PSS4_t - \underset{\substack{(-5.78)\\ [-0.21]}}{13.7327}(FEDSLT + NFSLT + CSLT + BSLT)_t$$

S/M = 0.0214

Table 1. Estimates of beef supply components (continued)

(15) Total commercial beef production

$$BPROD_t = AVECW_t(FEDSLT + NFSLT + CSLT + BSLT)_t$$

(16) Total beef production (commercial and farm slaughter)

$$TOTBSP_t = BPROD_t + FPD_t$$

[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.

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

Ratio	Quarter 1	Quarter 2	Quarter 3	Quarter 4
CALFCROP/COWHERD	0.3317 (0.0115)[a]	0.3168 (0.0097)	0.0818 (0.0025)	0.1744 (0.0043)
CATPL13/CALF2	0.1116 (0.0120)	0.1144 (0.0162)	0.1211 (0.0171)	0.1569 (0.0173)
CATFM13/(CATNF13 + CATPL13)	0.3689 (0.0171)	0.3668 (0.0177)	0.3788 (0.0217)	0.3381 (0.0156)
FEDSLT/CATFM13	1.1506 (0.0351)	1.1658 (0.0334)	1.1639 (0.0256)	1.1454 (0.0402)
NFSLT/CALF5	0.0161 (0.0104)	0.0194 (0.0095)	0.0216 (0.0116)	0.0227 (0.0100)

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 sample means.

Table 3. Estimates of demand components

(17) Retail beef demand (ITSUR)[a,b]

$$
\begin{aligned}
LOG(BEFCN_t) = {} & \underset{(-6.03)^{c}}{0.1873\ D6779} - \underset{(-2.86)}{0.06209(D2 * D6779)} - \underset{(-2.68)}{0.06526(D3 * D6779)} \\
& - \underset{(-2.95)}{0.07772(D4 * D6779)} + \underset{(2.73)}{0.07452\ D8084} - \underset{(-0.66)}{0.01768(D8084 * D2)} \\
& + \underset{(0.40)}{0.01090(D8084 * D3)} - \underset{(-1.46)}{0.04513(D8084 * D4)} - \underset{(-0.66)}{0.01966\ DUM85} \\
& - \underset{(-0.13)}{0.004652(DUM85 * D2)} + \underset{(0.01)}{0.0002968(DUM85 * D3)} \\
& - \underset{(-2.85)}{0.1065(DUM85 * D4)} + LOG(BEFCN_{t-4}) \\
& - \underset{(-6.83)}{0.5166}[LOG(RPBF4_t) - LOG(RPBF4_{t-4})] \\
& + \underset{(4.74)}{0.2303}[LOG(RPPK_t) - LOG(RPPK_{t-4})] \\
& - \underset{(-2.74)}{0.1390}[LOG(RPCK_t) - LOG(RPCK_{t-4})] \\
& - 0.00863[LOG(CPIFOOD_t) - LOG(CPIFOOD_{t-4})] \\
& + \underset{(2.18)}{0.04339}[LOG(FEXP_t) - LOG(FEXP_{t-4})] \\
& + (0.33 - 1)[LOG(BEFCN_{t-4}) \\
& + \underset{(-12.00)}{0.80223}\ LOG(RPBF4_{t-4}) - 0.2998\ LOG(RPPK_{t-4}) \\
& + \underset{(-1.60)}{0.02821}\ LOG(RPCK_{t-4}) + 0.5291\ LOG(CPIFOOD_{t-4}) \\
& - \underset{(3.50)}{1.0598}\ LOG(FEXP_{t-4})] \\
& S/M = 0.01^{d}
\end{aligned}
$$

Table 3. Estimates of demand components (continued)

(18) Real retail-farm margin (OLS)

$$
\begin{aligned}
RBMARGIN_t = {} & \underset{\substack{(18.43)\\ [0.43]}}{0.441}(RPBF4/CPI)_t * D1 + \underset{\substack{(18.24)\\ [0.43]}}{0.4343}(RPBF4/CPI)_t * D2 \\
& + \underset{\substack{(18.35)\\ [0.43]}}{0.439}(RPBF4/CPI)_t * D3 + \underset{\substack{(17.71)\\ [0.43]}}{0.4376}(RPBF4/CPI)_t * D4 \\
& + \underset{\substack{(3.21)\\ [0.05]}}{0.00208}(RPBF4/CPI)_t * (TOTBSP/POPN4)_t \\
& + \underset{\substack{(7.22)\\ [0.05]}}{0.0003246} * MKTCOST_t + \underset{\substack{(6.44)\\ [0.25]}}{0.2449} * RBMARGIN_{t-1}
\end{aligned}
$$

S/M = 0.0001

(19) Price of choice slaughter steers

$$PSS4_t = 100[RPBF4_t - (RBMARGIN_t * CPI_t)]$$

(20) Price of commercial utility cows (GLS)

$$
\begin{aligned}
PBW4_t = {} & \underset{(1.31)}{1.5652} + \underset{\substack{(25.27)\\ [0.83]}}{0.4686}\ PFC4_t + \underset{\substack{(3.89)\\ [0.12]}}{1.8058}\ PCO4_t + \underset{(2.00)}{0.6302}\ D2 + \underset{(0.41)}{0.1473}\ D3 \\
& - \underset{(-3.21)}{1.0161}\ D4 + - \underset{(-1.08)}{0.689}\ FREEZE_t
\end{aligned}
$$

S/M = 0.041 $\qquad u_t = \underset{(6.82)}{0.609} * u_{t-1} + \epsilon_t$

Table 3. Estimates of demand components (continued)

(21) Price of feeder steers, 400-500 lbs. (GLS)

$$PFC4_t = \underset{(-1.56)}{-3.6485} + \underset{\substack{(25.85)\\[0.95]}}{1.0473}\ PFCL4_t + \underset{\substack{(4.03)\\[0.15]}}{0.1618}\ PFCL4_{t-1}$$

$$- \underset{\substack{(-1.26)\\[-0.03]}}{0.7972}\ PCO4_t + \underset{(1.69)}{1.0428} + FREEZE_t + \underset{(2.36)}{0.6829}\ D2$$

$$- \underset{(-1.21)}{0.4203}\ D3 - \underset{(-3.87)}{1.1735}\ D4$$

$$S/M = 0.024 \qquad u_t = \underset{(15.05)}{0.861} * u_{t-1} + \epsilon_t$$

(22) Price of feeder steers, 600-700 lbs. (GLS)

$$PFCL4_t = \underset{(1.31)}{6.6224} + \underset{\substack{(10.61)\\[0.72]}}{0.7582}\ PSS4_t + \underset{\substack{(3.89)\\[0.26]}}{0.2801}\ PSS4_{t-1}$$

$$- \underset{\substack{(-1.57)\\[-0.09]}}{2.1105}\ PCO4_t - \underset{(-1.66)}{0.9761}\ D2 - \underset{(-2.64)}{1.8020}\ D3 - \underset{(-2.60)}{1.5679}\ D4$$

$$S/M = 0.054 \qquad u_t = \underset{(16.01)}{0.874} * u_{t-1} + \epsilon_t$$

(23) Closing cold-storage stocks (OLS)

$$ENDSTK_t = - \underset{\substack{(-3.40)\\[0.13]}}{22.078}\ RPBF4_{t-1} + \underset{\substack{(10.71)\\[0.65]}}{0.6489}\ BSTK_t + \underset{\substack{(3.61)\\[0.67]}}{0.0383}\ TOTBSP_t$$

$$+ \underset{\substack{(5.72)\\[0.38]}}{0.2583}\ IMP_t - \underset{(-3.17)}{183.766}\ D1 - \underset{(-3.67)}{209.940}\ D2$$

$$- \underset{(-3.88)}{229.290}\ D3 - \underset{(-2.45)}{146.529}\ D4$$

$$S/M = 0.095$$

Table 3. Estimates of demand components (continued)

(24) Beginning stocks

$BSTK_t = ENDSTK_{t-1}$

(25) Total beef domestic disappearance

$TOTBCN_t = TOTBSP_t + BSTK_t - ENDSTK_t + IMP_t - EXP_t - MILIT_t - SHIP_t$

(26) Per capita beef consumption

$BEFCN_t = (TOTBCN/POPN4)_t * BCONVERT$

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

[b]The retail beef demand was inverted to obtain the logarithm of the retail price of beef 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]S/M equals the standard error divided by the sample mean of the dependent variable.

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

Variable	Units	Label	Source[a]
Beef cow herd	million head	BEEFCOW	USDA, Cattle
Cow herd	million head	COWHERD	USDA, Cattle
Cow slaughter	million head	CSLT	USDA, Livestock and Poultry
Heifers added to the breeding herd	million head	HEIFERS	$COWHERD_{t+1} - 0.995 * COWHERD_t + CSLT_t$
Calf crop	million head	CALFCROP	USDA, Cattle
Calf crop--light weights	million head	CALF2	Calf Crop (lag 2-5)
Calf crop--medium weights	million head	CALF4	Calf Crop (lag 4-7)
Calf crop--heavier weights	million head	CALF5	Calf Crop (lag 5-8)
Cattle placed on feed--13 states	million head	CATPL13	USDA, Livestock and Poultry
Cattle on feed--13 states	million head	CATNF13	USDA, Livestock and Poultry
Cattle fed marketings--13 state	million head	CATFM13	USDA, Livestock and Poultry
Fed slaughter	million head	FEDSLT	USDA, Livestock and Poultry
Nonfed slaughter	million head	NFSLT	USDA, Livestock and Poultry
Average carcass weight	pounds	AVECW	USDA, Livestock and Poultry
Total commercial beef production	million head	BPROD	USDA, Livestock and Poultry
Total beef production	million head	TOTBSP	USDA, Livestock and Poultry
Omaha price of commercial utility cows	dollars/cwt	PBW4	USDA, Livestock and Poultry

Table 4. U.S. quarterly beef model variables (continued)

Variable	Units	Label	Source[a]
K.C. price of feeder steers, 400-500 pounds	dollars/cwt	PFC4	USDA, Livestock and Poultry
K.C. price of feeder steers, 600-700 pounds	dollars/cwt	PFCL4	USDA, Livestock and Poultry
Omaha slaughter steer price	dollars/cwt	PSS4	USDA, Livestock and Poultry
Retail beef price	dollars/pound	RPBF4	USDA, Livestock and Poultry
Real retail-farm margin	dollars/cwt	RBMARGIN	(100 RPBF4 - PSS4)/CPI
Closing cold-storage stocks	millions pounds	ENDSTK	USDA, Livestock and Poultry
Beginning stocks	millions pounds	BSTK	USDA, Livestock and Poultry
Total beef domestic disappearance	millions pounds	TOTBCN	USDA, Livestock and Poultry
Per capita consumption	pounds	BEFCN	(TOTBCN/POPN4) * BCONVERT
Dairy cow herd	million head	DAIRYCOW	USDA, Livestock and Poultry
Bull slaughter	million pounds	BSLT	USDA, Livestock and Poultry
Farm beef production	million pounds	FPD	USDA, Livestock and Poultry
Beef imports	million pounds	IMP	USDA, Livestock and Poultry
Beef exports	million pounds	EXP	USDA, Livestock and Poultry
Beef military use	million pounds	MILIT	USDA, Livestock and Poultry
Beef shipments	million pounds	SHIP	USDA, Livestock and Poultry

Table 4. U.S. quarterly beef model variables (continued)

Variable	Units	Label	Source[a]
Retail price of chicken	dollars/pound	RPCK	USDA, Livestock and Poultry
Retail price of pork	dollars/pound	RPPK	USDA, Livestock and Poultry
Beef carcass-retail weight conversion ratio		BCONVERT	USDA, Livestock and Poultry
Dummy variable, 1972	If < 1973 = 1 If ≥ 1973 = 0	DUM72	
Dummy variable, 1973	If < 1974 = 1 If ≥ 1974 = 0	DUM73	
Dummy variable, 1974	If < 1975 = 1 If ≥ 1975 = 0	DUM74	
Dummy variable, 1985	If < 1985 = 0 If ≥ 1985 = 1	DUM85	
Dummy variable, 1980-84	If < 1980, < 1985 = 1 If > 1980, > 1985 = 0	D8084	
Dummy variable, 1967-79	If < 1967, < 1980 = 1 If > 1967, > 1980 = 0	D6779	
Dummy variable for Nixon price freeze	1 if year = 1973.25 1973.50; 0 otherwise	FREEZE	
Seasonal dummy variables		D1,D2,D3,D4	
Index of meat packers hourly earnings	1967 = 100	IMPHRE	U.S. Department of Commerce, Employment and Earnings
Producer price index of fuels 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	1965.00 = 1.00, etc.	T65	
Log of trend variable		LT65	LOG(T65)

Table 4. U.S. quarterly beef model variables (continued)

Variable	Units	Label	Source[a]
Consumer price index	1967 = 100	CPI	U.S. Department of Commerce, Survey of Current Business
Corn price	dollars/bushel	PC04	USDA, Agricultural Prices
Interest rate on feed cattle loans	percent	IFCL	Federal Reserve Bank, 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

Variables	Label	Static RMPSE[a]	Dynamic RMPSE
Cow herd	COWHERD	0.00	6.37
Beef herd	BEEFCOW	0.10	8.04
Heifers added	HEIFERS	14.01	15.04
Calf crop	CALFCROP	3.37	5.78
Cow slaughter	CSLT	14.33	25.87
Fed slaughter	FEDSLT	5.21	6.12
Nonfed slaughter	NFSLT	67.34	52.09
Cattle placements--13 states	CATPL13	8.69	8.29
Cattle on feed--13 states	CATNF13	4.06	9.54
Cattle fed marketings--13 states	CATFM13	5.17	6.27
Total beef supply	TOTBSP	3.88	6.44
Retail-farm margin	BMARGIN	5.58	10.22
Slaughter steer price	PSS4	17.56	20.66
Feeder steer price, 400-500 pounds	PFC4	12.56	26.30
Feeder steer price, 600-700 pounds	PFCL4	12.90	22.97
Utility cow price	PBW4	10.70	20.93
Retail beef price	RPBF4	8.58	12.67
Per capita consumption	BEFCN	3.47	5.89

NOTE: Historical simulation was made over the period 1970.00 - 1986.75.

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

Table 6. Selected beef model variable responses to a 10 percent increase in feed costs (PC04)

Period	TOTBSP	FEDSLT	NFSLT	CSLT	CATFM13	CATPL13	CALFCROP	COWHERD	HEIFERS	RPBF4	PSS4	BEFCN
						(Percentage Change)						
1	0.26	0.18	0.00	1.79	0.18	0.00	0.00	0.00	0.00	-0.46	-0.92	0.24
2	0.20	-0.74	3.67	3.41	-0.74	-2.33	-0.06	-0.06	0.00	-0.37	-0.55	0.19
3	0.31	-1.28	7.33	5.13	-1.28	-2.23	-0.18	-0.18	0.00	-0.55	-0.90	0.28
4	0.50	-1.65	11.04	7.03	-1.65	-2.34	-0.37	-0.37	-0.55	-0.89	-1.50	0.46
5	0.51	-1.98	14.91	6.81	-1.98	-2.54	-0.64	-0.64	-1.06	-0.76	-1.10	0.48
10	-0.29	-2.69	12.43	3.05	-2.69	-2.87	-2.02	-2.02	-2.71	0.77	1.31	-0.25
20	-1.77	-3.76	4.64	-2.22	-3.76	-3.88	-3.12	-3.12	-3.37	2.38	3.64	-1.68
30	-2.13	-4.10	3.09	-3.23	-4.10	-4.13	-3.39	-3.39	-3.60	2.66	4.40	-2.04
∞	-2.30	-4.25	2.34	-3.73	-4.25	-4.25	-3.52	-3.52	-3.70	2.81	4.32	-2.20

NOTE: Values represent approximate total elasticities with respect to feed costs. The elasticities allow for demand and supply adjustments within the beef 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 beef model variable responses to a 10 percent increase in the interest rate (RIFCL)

Period	TOTBSP	FEDSLT	NFSLT	CSLT	CATFM13	CATPL13	CALFCROP	COWHERD	HEIFERS	RPBF4	PSS4	BEFCN
						(Percentage Change)						
1	0.19	0.32	0.00	0.53	0.32	0.00	0.00	0.00	0.00	-0.33	-0.66	0.17
2	0.17	0.13	0.19	0.99	0.13	-0.18	-0.02	-0.02	0.00	-0.31	-0.48	0.16
3	0.19	0.04	0.39	1.44	0.04	-0.13	-0.05	-0.05	0.00	-0.34	-0.52	0.18
4	0.22	-0.03	0.59	1.92	-0.03	-0.14	-0.10	-0.10	-0.38	-0.40	-0.62	0.21
5	0.20	-0.09	0.80	1.70	-0.09	-0.18	-0.19	-0.19	-0.74	-0.24	-0.28	0.19
10	-0.05	-0.20	-0.34	0.40	-0.20	-0.26	-0.65	-0.65	-1.53	0.19	0.32	-0.04
20	-0.55	-0.60	-2.86	-1.38	-0.60	-0.64	-1.09	-1.09	-1.82	0.74	1.14	-0.52
30	-0.71	-0.74	-3.56	-1.84	-0.74	-0.76	-1.21	-1.21	-1.92	0.87	1.34	-0.67
∞	-0.78	-0.81	-3.91	-2.07	-0.81	-0.81	-1.27	-1.27	-1.97	0.94	1.44	-0.75

NOTE: Values represent approximate total elasticities with respect to real interest rate. The elasticities allow for demand and supply adjustments within the beef 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 beef model variable responses to a 10 percent increase in retail price of pork (RPPK)

Period	TOTBSP	FEDSLT	NFSLT	CSLT	CATFM13	CATPL13	CALFCROP	COWHERD	HEIFERS	RPBF4	PSS4	BEFCN
						(Percentage Change)						
1	0.11	-0.14	0.00	-2.64	-0.14	0.00	0.00	0.00	0.00	4.07	7.64	0.13
2	0.06	0.68	-2.16	-4.56	0.68	2.04	0.09	0.09	0.00	4.19	5.98	0.08
3	-0.13	1.01	-4.65	-6.45	1.01	1.59	0.25	0.25	0.00	4.54	6.17	-0.10
4	-0.35	1.24	-7.00	-8.42	1.24	1.67	0.48	0.48	0.74	4.96	6.73	-0.30
5	-0.17	1.36	-9.46	-9.83	1.36	1.88	0.81	0.81	1.32	8.44	12.99	-0.12
10	0.40	3.50	-14.47	-9.80	3.50	3.88	3.32	3.32	4.78	7.11	6.50	0.36
20	3.61	5.92	2.76	2.67	5.92	6.27	6.69	6.69	6.99	2.84	2.73	3.41
30	4.79	7.13	8.04	6.26	7.13	7.25	7.69	7.69	7.80	1.91	0.82	4.55
∞	5.40	7.76	10.78	8.24	7.76	7.76	8.24	8.24	8.24	1.38	0.00	5.15

NOTE: Values represent approximate total elasticities with respect to the retail price of pork. The elasticities allow for demand and supply adjustments within the beef 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 beef model variable responses to a 10 percent increase in retail price of broilers (RPCK)

Period	TOTBSP	FEDSLT	NFSLT	CSLT	CATFM13	CATPL13	CALFCROP	COWHERD	HEIFERS	RPBF4	PSS4	BEFCN
						(Percentage Change)						
1	0.04	-0.05	0.00	-1.04	-0.05	0.00	0.00	0.00	0.00	1.60	2.99	0.05
2	0.02	0.27	-0.85	-1.81	0.27	0.80	0.04	0.04	0.00	1.64	2.35	0.03
3	-0.05	0.40	-1.83	-2.58	0.40	0.63	0.10	0.10	0.00	1.79	2.43	-0.04
4	-0.14	0.49	-2.75	-3.39	0.49	0.66	0.19	0.19	0.29	1.95	2.65	-0.13
5	-0.13	0.59	-3.72	-2.85	0.59	0.74	0.32	0.32	0.56	1.54	1.78	-0.12
10	0.24	0.68	-1.54	-0.75	0.68	0.75	0.84	0.84	1.01	0.81	0.85	0.22
20	0.71	1.07	0.95	0.78	1.07	1.11	1.17	1.17	1.20	0.38	0.24	0.67
30	0.83	1.19	1.45	1.13	1.19	1.20	1.27	1.27	1.28	0.28	0.09	0.79
∞	0.89	1.25	1.74	1.33	1.25	1.25	1.33	1.33	1.33	0.23	0.00	0.85

NOTE: Values represent approximate total elasticities with respect to the retail price of broilers. The elasticities allow for demand and supply adjustments within the beef 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. Beef supply elasticities from selected studies

Study	Estimation Period	Fed	Nonfed	Beef
Cromarty (1959)	1929-1953	--	--	0.037
Reutlinger (1966)	1947-1962	--	--	-0.17[a]
Langemeier and Thompson (1967)	1947-1963	0.232	-0.552	0.16
Tryfos (1974)	1951-1971	--	--	-0.01[a]
Freebairn and Rausser (1975)	1956-1971	0.00	0.61	0.14
Shuib and Menkhaus (1977)	1950-1974	0.14	-0.97	--
Ospina and Shumway (1979)	1956-1975	--	--	0.14
Brester and Marsh (1983)	1960-1980	-0.192	-1.25	--
CARD (1989)	1967-1986	0.13[a]	-0.53[a]	-0.03[a] 0.16

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

[a]The figures within parentheses indicate the standard error.

Table 12. Summary of estimated elasticities by different studies

Study	Data	Period	Demand Specifications	Own-price[a]	Elasticities 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 BC 0.07 PB 0.08 PC 0.04 CB 0.20 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 BC -0.07 PB -0.08 PC 0.10 CB -0.03 CP 0.21
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 BC -0.01 PB 0.32 PC 0.19 CB 0.29 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 BC -0.11 PB 0.28 PC 0.20 CB 0.54 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 BC -0.20 PB 0.60 PC 0.15 CB 0.08 CP 0.0
			long run	Beef -0.43 Pork -0.84 Chik -0.30	0.45 0.18 1.06	BP 0.20 BC -0.17 PB 0.40 PC 0.10 CB 0.18 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 BC 0.04 PB 0.26 PC 0.04 CB 0.24 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 BC 0.07 PB 0.22 PC 0.06 CB 0.26 CP 0.22
			with structural change	Beef -0.62 Pork -0.72 Plty -0.58	0.18 0.43 0.28	BP 0.36 BC 0.08 PB 0.22 PC 0.08 CB 0.30 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 BC 0.06 PB 0.19 PC 0.09 CB 0.29 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 BC 0.05 PB 0.31 PC 0.007 CB 0.25 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 beef model, 1987.00 to 1987.75

Variable	Label	RMPSE[a]
Heifers added to the breeding herd	HEIFERS	0.25
Cow herd	COWHERD	0.01
Cow slaughter	CSLT	0.25
Calf crop	CALFCROP	0.01
Fed slaughter	FEDSLT	0.10
Nonfed slaughter	NFSLT	0.73
Cattle fed marketings--13 states	CATFM13	0.10
Cattle placed on feed--13 states	CATPL13	0.14
Price of feeder steers, 400-500 lbs.	PFC4	0.15
Price of feeder steers, 600-700 lbs.	PFCL4	0.16
Price of utility cows	PBW4	0.13
Price of slaughter steers	PSS4	0.28
Retail price of beef	RPBF4	0.12
Total beef production	TOTBSP	0.14
Closing cold-storage stocks	ENDSTK	0.27

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

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

Endnotes

1. Arizona and California comprise the southwestern sector; the Corn Belt-Lake States are, Michigan, Minnesota, Wisconsin, Iowa, Indiana, Ohio, Illinois, and Missouri; and the Plains States are, Texas, Kansas, Oklahoma, Colorado, New Mexico, Nebraska, and South Dakota.

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

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