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A DYNAMIC ANALYSIS OF DEMAND AND SUPPLY RELATIONSHIPS FOR THE U.S. BEEF CATTLE INDUSTRY AND THEIR POLICY IMPLICATIONS

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ABSTRACT

This paper develops a dynamic, simultaneous model to describe the relationships within and among the feeder cattle, slaughter cattle, and wholesale-retail beef markets of the U.S. beef cattle industry. The model is estimated by means of three-stage least squares with quarterly data for 1963-1983.

Parameter estimates indicate that beef heifer replacements, beef cow inventories, beef cattle supplies, beef supplies, and beef imports only partially adjust toward their long-run levels in the short run. However, prices at all three levels interact simultaneously to establish interim, short-run equilibria. Derived elasticity and flexibility estimates for supply and demand functions with respect to own prices (quantities) suggest that the U.S. beef cattle industry is not very sensitive to changes in prices in the short run, but becomes more responsive in the long run.

INTRODUCTION

Beef cattle numbers and beef production grew substantially during the 1950s and 1960s. During this period, increased beef production was associated with expansion of the cattle feeding sector. Positive feeding margins, ample supplies of feed grains, and strong demand for beef from grain-fed cattle provided incentives for rapid expansion of the industry. However, the situation reversed during the 1970s due to erratic feed grain supplies and sharply increased feeding costs. Consequently, the U.S. beef cattle industry has grown little since 1975.

On the demand side of the market, beef consumption has declined sharply since 1976. Per capita consumption of beef dropped from a record 94.4 pounds in 1976 to 78.8 pounds in 1983 (American Meat Institute) as consumers switched to chicken and other meats. While beef continues to be preferred by many Americans, its consumption mix has changed. Approximately 40 percent of beef consumed in the United States during the 1970s was in the form of nonfed beef, particularly ground beef (Brunk). Some industry analysts believe that this proportion will continue to rise over the 1980s as more weight- and health-conscious consumers switch to lean ground beef and poultry (Van Arsdall, Gustafson, and Jones).

This paper summarizes an econometric model of the U.S. beef cattle industry with emphasis on changes that have taken place since the 1970s. Full details of the model are presented in Bedingar. The model quantifies the dynamic structure generating prices in major market sectors and the role that these prices play in guiding decisions of cattle producers, processers, retailers, and other market participants.

RESEARCH PROCEDURES

Specification of the econometric model estimated in this study involves the application of economic theory, and knowledge of the biological and institutional characteristics of beef cattle production and marketing to identify important variables affecting the U.S. beef cattle industry. Key economic relationships are described by a series of mathematical equations forming the foundation of the industry model. This model is specified as a quarterly simultaneous model and encompasses supply, demand, inventories, imports, and prices.

The U.S. beef cattle industry approaches the economic ideal of a purely competitive market in the sense that cattle producers and buyers are price takers. Prices, therefore, are determined by the interaction of aggregate supply and demand. No separate price equations are included in the model because of this assumption of competitive equilibrium. Instead, demand functions are normalized with respect to prices, while quantities are specified by supply functions. Quantities demanded are determined by market clearing identities.

For purposes of modeling, the beef cattle industry is divided into three subsector markets: (1) the feeder cattle market, (2) the slaughter cattle market, and (3) the wholesale-retail beef market. Demands, supplies, and prices are determined simultaneously in all three subsectors. Subsectors (2) and (3) are also disaggregated into fed and nonfed cattle and beef categories. Some previous studies have also taken this approach, while others have classified beef according to its end use (table-ready beef versus beef going into processed food products). The fed/nonfed approach requires estimates of the quantity of beef originating from feedlots (fed beef) and treats it separately from nonfed beef originating from cull cows, bulls, and steers and heifers reared on pastures but never sent to feedlots. The end-use approach measures the quantities of high/low grade beef entering the market by applying appropriate yield percentages to various types of animals slaughtered. These yield percentages are obtained from trade sources and are assumed to remain constant (Bain). While each approach has its limitations, the production-oriented approach using fed/nonfed measures is used because it provides more insight into the coordination of industry subsectors than the end-use method.

Other sectors of agriculture (notably feedgrains) and the general economy are treated as exogenous in this study. Equations are specified in terms of cattle numbers for feeder and slaughter cattle markets. Wholesale-retail market equations are specified in per capita carcass weight equivalents of retail cuts consumed. Per capita measures are used for the wholesale-retail subsector, because the underlying theory of consumer choice refers primarily to individuals, and also because per capita relationships are likely to be more stable than relationships between aggregates (Houthakker and Taylor, p. 29).

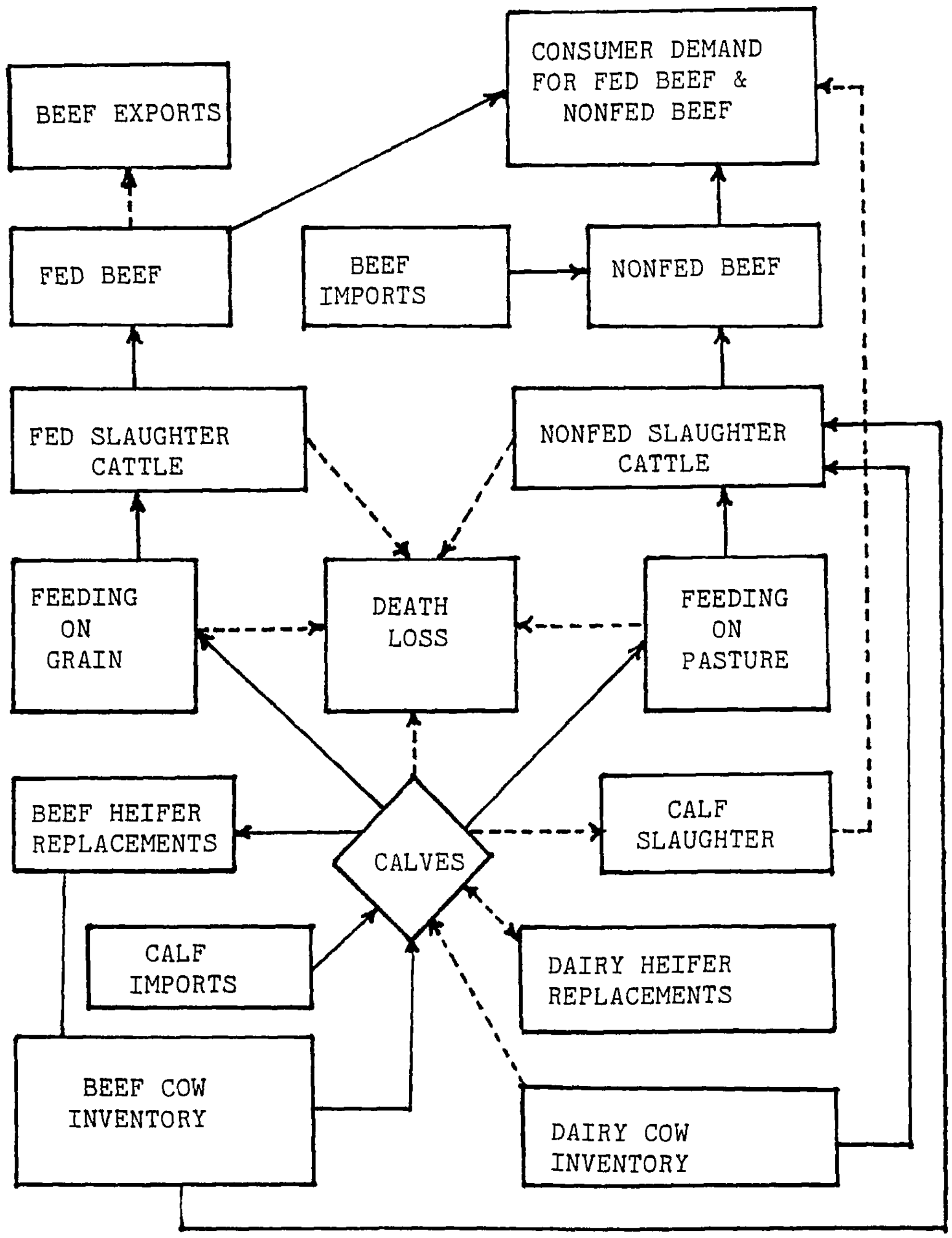
STRUCTURE OF THE U.S. BEEF CATTLE INDUSTRY

The economic structure of the U.S. beef cattle industry is complex, both in terms of the diverse nature of the resources employed and of its products and in the time frames in which competitive interactions take place. In some phases of the industry demands and supplies interact simultaneously, while in others lags extending over several years are encountered. Perhaps no single study can consider all the variables that could, at some level of detail, be considered as endogenous to the industry. Figure 1 displays a flow diagram of the major products and processes in the industry. Solid-lined connecting arrows show the relationships to be analyzed in this study, and the broken lines show those treated as exogenous.

Beef production involves two major groups of livestock producers, cow-calf operators and feedlot operators. Cow-calf operators maintain beef cow herds and raise calves. They determine how many cows to breed and whether to sell calves at weaning or to retain them on pasture for further growth before selling them to feedlots. Some specialist producers, called backgrounders or stocker operators, purchase weaned calves for placement on pasture. Most of these cattle are eventually sold to feedlots. Feedlot operators purchase feeder cattle and calves at varying weights and feed them to slaughter weight and condition for sale as fed beef. Nonfed beef originates from cull cows and bulls and other cattle not placed in feedlots and comes from cow-calf operations and from dairy producers. To estimate supplies of fed and nonfed beef, this study specifies a series of behavioral relationships encompassing feeder cattle production, cattle feeding, beef output, and beef consumption as indicated in Figure 1.

Little vertical integration or non-market vertical coordination is found in the beef cattle industry, so market transactions take place at many different levels. Accordingly, this study specifies

Figure 1: Major Product Flows in the U.S. Beef Cattle Industry.



that prices are jointly determined within the three market subsectors described previously. Thus, feeder cattle price, slaughter cattle prices, and the retail prices of fed and nonfed beef are specified to be determined simultaneously. Retail beef demand is affected by prices of substitutes, consumer income, and institutional relationships involved in consumer demand. Major retail outlets for beef are retail grocers for at-home consumption, but hotel, restaurant, and institutional outlets for away-from-home consumption are also important. The usefulness of maintaining distinctions between fed and nonfed beef at the retail level is illustrated by the data in Table 1. Most nonfed beef is consumed as hamburger, and most fed beef grades choice, so the consumption and price data represent these beef classes. Table 1 shows that quantities and prices of hamburger and choice beef do not vary in strict proportion, so maintaining distinctions between these classes of beef should provide added information about the industry.

Fed and nonfed beef are homogenous products, and there are relatively large numbers of buyers and sellers at each level of the industry. Imported beef, which is virtually all nonfed beef, is also homogeneous. Until now, product differentiation has succeeded only for a few specialized processed products and represents a very small proportion of beef marketings. This may change in the future, but at present beef and beef cattle prices reflect perceived quality with no differentiation between producers. Thus, market participants are price takers in the sense that they cannot exact price premiums after allowances for transportation costs and quality differences.

Table 1. Hamburger and Beef: Per Capita Consumption and Prices.

	Quantities		Prices	
	Hamburger	Choice Beef	Hamburger	Choice Beef
	retail weight pounds per capita		dollars per pound	
1971	16.7	57.4	0.68	1.08
1972	16.5	59.6	0.74	1.19
1973	16.2	55.2	0.96	1.42
1974	19.6	54.9	0.97	1.46
1975	23.5	51.2	0.88	1.55
1976	23.7	57.4	0.88	1.48
1977	22.3	56.9	0.85	1.48
1978	20.1	55.5	1.11	1.82
1979	17.2	51.1	1.55	2.26
1980	18.0	48.4	1.58	2.38

Source: American Meat Institute, Meat Facts, Washington, D.C.:American Meat Instiute, 1984, p. 19.

THE ECONOMIC MODEL

Basic explanatory relationships are specified in the model on the basis of the flow relationships previously illustrated and on economic theory. The model specification follows the U.S. beef production process and distinguishes the three major subsectors discussed above. Key endogenous variables in each subsector are identified and behavioral equations are specified for them. The expected behavior of explanatory variables is determined by economc theory and, for supply, by biological factors in beef cattle production.

Feeder Cattle Market

Calf Crop

Calves are predominantly the offspring of breeding activities in the previous year. While virtually all cows are bred, the calving rate (calves born as a percentage of cows) is influenced by management. Bobst and Davis (1984) found that prices and costs accounted for much of the deviations from mean calving rates. Consequently, the annual crop of calves (YCC)[1] is specified as a function of the breeding herd (beef and dairy cows) on December 31 of the preceding year (XBD), feeder cattle price (YP1), an index of

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[1]Letter code designations for variables are given in parentheses at their first mention in the text. Thereafter, they are referred to by name in the text and by letter code in equations. Endogenous variables are prefixed by "Y" and exogenous variables by "X". See Tables 2-4 for full variable definitions.

forage output (XFO), and a feed price index (XPF) all lagged one year:

$$YCC_t = f(XBD_{t-1}, YPI_{t-1}, XFO_{t-1}, XPF_{t-1}). \quad (1)$$

The annual calf crop is expected to increase with increases in the size of breeding herd, forage output, and feeder cattle price, but a negative relationship is expected with the feed price index.

Although calves are born year around, calf crop data are available only on an annual basis. To generate quarterly estimates of the calf crop, annual observations are multiplied by animal scientists' estimated seasonal distribution (Neumann, p. 153). This function is

$$YCC_{tq} = d_q \, YCC_t. \quad (2)$$

Feeder Cattle Inventory

Feeder cattle inventory (YFI) is defined by an identity equation measuring end-of-quarter numbers of feeder cattle on farms, but not in feedlots. Additions to the feeder cattle inventory during a quarter are from the current calf crop and feeder cattle imports (YFM). Shipments to feedlots (YFP), designation of heifers as beef and dairy replacements (YBR and XDR), calf slaughter (XCS), death loss (XDL), and nonfed steer and heifer slaughter (XNS) all reduce feeder cattle inventory. This identity is

$$YFI_{tq} = YFI_{tq-1} + YCC_{tq} + YFM_{tq} - YFP_{tq} - YBR_{tq} - XDR_{tq} - XCS_{tq} - XDL_{tq} - XNS_{tq}. \quad (3)$$

Equation (3) is a balance sheet equation intended to indicate sources and disposition of feeder cattle among mutually exclusive purposes.

Beef Heifer Replacements

Heifers serve both as capital goods and as consumption goods (Reutlinger; Jarvis; Nelson and Spreen). Some are selected for breeding and the rest are designated for feeding and slaughter. Consequently, the demand for beef heifer replacements (YBH) is treated as competitive with heifer feeding and/or slaughter and is influenced by expected feeder cattle price ($YP1^e$), beef cow inventories to replace culled cows (YBC), current range and pasture conditions (XRC), and seasonality (S). This function is

$$YBH_{tq} = f(YP1^e_{tq},\ YBC_{tq},\ XRC_{tq},\ S_q). \tag{4}$$

Demand for beef heifer replacements is expected to be positively related to expected feeder cattle price, range conditions, and the beef breeding herd.

Beef Cow Inventories

Beef cows can either be retained for an additional year of breeding or be sent to slaughter, depending on their age and on profitability considerations. Thus, expected costs and returns create incentives to increase, maintain, or reduce the size of the breeding herd. Beef cow inventories are therefore specified as a function of expected feeder cattle price, current nonfed slaughter cattle price (YP2), beef heifer replacements, cropland acreage (XCA), previous range and pasture conditions, and dummy variables for seasonal variation:

$$YBC_{tq} = f(YP1^{e}_{tq},\ YP2_{tq},\ YBH_{tq},\ XCA_{tq},\ XRC_{tq-i},\ S_q). \qquad (5)$$

Expected relationships are positive with respect to expected feeder cattle prices and negative with respect to nonfed slaughter cattle prices. An inverse relationship with cropland acreage and a positive relationship with lagged range and pasture condition are expected. Crop acreage is interpreted as a proxy variable for measuring changes in the forage base supporting beef cattle production (Bobst and Davis, 1987; Heimlich).

Feeder Cattle Imports

Feeder cattle are imported from Canada and Mexico for feedlot placement, although some may be backgrounded first. Since feeding profitability motivates the importation of feeder cattle, imports are specified as a function of the current fed slaughter cattle price (YP3), corn price (XPC), the import unit value (XUV), and seasonality:

$$YFM_{tq} = f(YP3_{tq},\ XPC_{tq},\ XUV_{tq},\ S_q). \qquad (6)$$

Import unit value is used to account for exchange rate differences between the United States and the exporting countries.

Feeder Cattle Supply to Feedlots

The supply of feeder cattle for feedlot placements from cow-calf and backgrounding operations (YFS) is specified to reflect opportunity costs of retention on pasture for an additional period. This function is

$$YFS_{tq} = (YP1_{tq},\ YFI_{tq},\ YP2^{e}_{tq},\ XIR_{tq},\ S_{q}). \tag{7}$$

Feeder cattle supply is expected to be inversely related to expectations about future nonfed cattle prices, but positively associated with current feeder prices, inventories, and interest rates.

<u>Feedlot Placements</u>

Feeder cattle are the most important input in the production of fed cattle. Input demand theory suggests that feedlot operators' demand for feeder cattle is a function of input and output prices. Therefore, the demand for feeder cattle is specified as

$$YFP_{tq} = f(YP1_{tq},\ YP3^{e}_{tq},\ XPC_{tq},\ XIR_{tq}). \tag{8}$$

Placements are expected to be inversely related to feeder cattle price, interest rates, and corn prices but positively related to expectations about future fed slaughter cattle prices.

Slaughter Cattle Market

This subsector consists of an inventory identity for cattle on feed and demand and supply functions for fed and nonfed slaughter cattle. Separate functions are specified for cattle slaughter and for beef output even though most recent beef cattle models have specified beef supply as single functions of prices and cattle numbers (Ospina and Shumway; Freebairn and Rausser; Arzac and Wilkinson). Langemeier and Thompson specified a separate cattle slaughter function, but their beef output function held carcass weight per head constant. The purpose of separate functions is to distinguish between factors affecting slaughter numbers and those affecting slaughter weights.

Cattle on Feed

Cattle on feed (YCF) is the inventory of cattle being fed and is the source of fed cattle supplied for slaughter (YSF). The inventory relationship is specified as an identity as follows:

$$YCF_{tq} = YCF_{tq-1} + YFP_{tq} - YSF_{tq}. \qquad (9)$$

Feedlots experience death losses and, occasionally, individual animals must be removed from feedlots and returned to pasture or slaughtered as nonfed cattle, but these are minor quantities and are ignored in this study.

Fed Cattle Supply

Feedlot operators have some flexibility in determining the weights at which they market cattle and therefore some control over the timing of sales. Consequently, the supply of fed cattle for slaughter is expected to respond to both current and expected future fed cattle prices, to inventories of cattle on feed, and to input costs, here represented by current corn prices and interest rates:

$$YSF_{tq} = f(YP3^{e}_{tq}, YP3_{tq}, YCF_{tq}, XPC_{tq}, XIR_{tq}). \qquad (10)$$

Fed cattle marketings are expected to be positively influenced by expected fed cattle price and numbers of cattle on feed but inversely related to current fed cattle price, corn price and interest rates. The hypothesized relationship with current price seems perverse, but it is documented in the literature (Nelson and Spreen).

Demand for Fed Slaughter Cattle

The demand for fed slaughter cattle by packers (YDF) is derived from the demand for fed beef in competition with its close substitute, nonfed beef. Fed cattle demand is also affected by packer costs. It is specified as a function of current fed and nonfed slaughter cattle prices, fed beef price (YP4), meatpacking wage rates (XWR), and interest rates:

$$YDF_{tq} = f(YP2_{tq}, YP3_{tq}, YP4_{tq}, XIR_{tq}, XWR_{tq}). \quad (11)$$

Increases in nonfed cattle prices and fed beef prices should increase the quantity of fed slaughter cattle demanded, while increases in wage and interest rates should reduce it.

Nonfed Slaughter Cattle Supply

Nonfed slaughter cattle (YSN) include cull beef and dairy cows, bulls, stags, and grass-fed steers and heifers. Nonfed cattle marketings are specified as a function of current and expected nonfed cattle prices, feeder cattle inventories, beef and dairy cow inventories (XDC), corn prices, current range and pasture conditions, and seasonality:

$$YSN_{tq} = f(YP2^{e}_{tq}, YP2_{tq}, YFI_{tq}, YBC_{tq}, XDC_{tq}, XRC_{tq}, S_{tq}). \quad (12)$$

Nonfed slaughter cattle supply should be inversely related to expected future nonfed cattle prices but positively related to current prices. Inverse relationships with feeder cattle and beef cow inventories can be expected, as well as with dairy cow inventories and corn prices. Range and pasture conditions should also be inversely related, because good conditions encourage producers to feed their animals to heavier weights, thus deferring slaughter (Bain).

Demand for Nonfed Slaughter Cattle

Specification of the demand for nonfed slaughter cattle (YDN) is identical to the specification for fed slaughter cattle demand, except that it is derived from the demand for nonfed beef. Substituting nonfed beef price (YP5) for fed beef price, the specification is

$$YDN_{tq} = f(YP2_{tq}, YP3_{tq}, YP5_{tq}, XWR_{tq}, XIR_{tq}). \quad (13)$$

Coefficient signs should be the same as in equation (11).

Wholesale-Retail Beef Market

Demand and supply functions for fed and nonfed beef are specified in per capita terms and measured on a carcass weight basis. Beef output and consumption are disaggregated into fed and nonfed categories. Demand relationships are specified to reflect substitution between fed and nonfed beef as well as between beef and other competing meats. As stated previously, these demand functions are normalized with respect to prices. The per capita specification of this subsector introduces nonlinearity into the model, because the quantity variables here are linked to the other subsectors through multiplicative relationships with current population. These multiplicative relationships do not affect parameter estimation, but they do have to be taken into account in applications of the model.

Per Capita Fed Beef Supply

The fed beef supply (YSC) function is a companion to the fed cattle slaughter function, equation (10). Per capita fed beef supply is specified as a function of numbers of fed cattle slaughtered, fed cattle price, and feeding costs per hundred pounds of gain:

$$YSC_{tq} = f(YSF_{tq}, YP3_{tq}, XCG_{tq}). \qquad (14)$$

This specification follows Boost and Davis (1984), but, as previously discussed, is different from most previous studies. Fed cattle marketings and the fed cattle price are expected to have positive coefficients, but a negative coefficient is expected for feeding costs. Price and costs are hypothesized to affect quantity supplied through varying carcass weights in response to changes in feeding profitability.

Per Capita Demand for Fed Beef

The specification of fed beef demand adopts the concept of a separable utility function and its corresponding two-stage approach to consumers' utility maximization. In this approach, demand functions for individual commodities are specified in terms of their own prices, prices of other commodities within their group, and group expenditures, in this case per capita expenditures for red meats and poultry (Phlips, p. 73).

In applying this approach to the model, per capita expenditures on red meats and poultry are taken as exogenous and used in place of the more conventional per capita income in the demand equations.

Demand for fed beef is specified in terms of its own price (YP4), prices of nonfed beef (YP5), pork (XPP), chicken (XPB), and per capita meat expenditures (XME):

$$YDC_{tq} = f(YP4_{tq}, YP5_{tq}, XPP_{tq}, XPB_{tq}, XME_{tq}). \quad (15)$$

All variables are expected to have a positive influence on the demand for fed beef except for its own price. Symmetry conditions are not imposed on cross-price coefficient estimates.

Per Capita Domestic Nonfed Beef Supply

Nonfed beef is supplied from the slaughter of domestic nonfed cattle and also from imported beef. Domestic nonfed beef supply (YSD) is primarily determined by nonfed cattle marketings. However, its specification also allows for changes in carcass weights due to nonfed cattle prices, range and pasture conditions in the previous quarter, and seasonality:

$$YSD_{tq} = f(YSN_{tq}, YP2_{tq-1}, XRC_{tq-1}, S_q). \quad (16)$$

Expected coefficient signs are positive for the first three explanatory variables. No expectations are developed for seasonal effects.

Per Capita Beef Imports

Beef imports (YBM) are specified as a function of domestic nonfed beef supply, nonfed beef price, annual import quotas (XIQ), interest rates and seasonal dummy variables:

$$YBM_{tq} = f(YSD_{tq}, YP5_{tq}, XIQ_t, XIR_{tq}, S_q). \quad (17)$$

This specification treats beef imports as supplemental to domestic nonfed beef supply. Most recent studies treat imports as predetermined by the import quota (Freebairn and Rausser; Bain; Arzac and Wilkinson; Boost and Davis, 1984). However, import quotas are annual quantities, leaving the distribution of beef imports within a given year to the discretion of importers. Thus, beef imports may be responsive to short-run economic factors, even though they are restricted on an annual basis.

Domestic nonfed beef output is included in the specification of equation (17), because, under the provisions of the Meat Import Act of 1979 (Conable), they in part determine import quotas.

Per Capita Nonfed Beef Supply

Per capita nonfed beef supply (YSD) is defined as the sum of per capita domestic nonfed beef supply and per capita beef imports:

$$YSH_{tq} = YSD_{tq} + YBM_{tq} \tag{18}$$

Equation (18) does not include changes in beef stocks because available stocks data do not distinguish between fed and nonfed beef.

Per Capita Demand for Nonfed Beef

The nonfed beef demand (YDH) function has the same explanatory variables as the fed beef function plus away-from-home food expenditures as a percentage of all food expenditures (XAF). This variable is included as a proxy for a structural change in demand favoring fast food restaurants (and hamburgers) over at-home consumption. The specification is

$$YDH_{tq} = f(YP4_{tq}, YP5_{tq}, XPP_{tq}, XPB_{tq}, XME_{tq}, XAF_{tq}). \quad (19)$$

All coefficients are expected to be positive except for own-price.

Market Clearing Identities and Price Expectations

Market clearing identities and price expectations functions are added to complete the specification of the model. Market clearing identities are required at each subsector level and for each class of cattle and beef. These identities are as follows:

a. Feeder cattle: $YFP_{tq} = YFS_{tq}.$ (20)

b. Fedslaughter cattle: $YDF_{tq} = YSF_{tq}.$ (21)

c. Nonfed slaughter cattle: $YDN_{tq} = YSN_{tq}.$ (22)

d. Fed beef: $YDC_{tq} = YSC_{tq}.$ (23)

e. Nonfed beef: $YDH_{tq} = YSH_{tq}.$ (24)

Price Expectations

The expected price variables in the model must be respecified as functions of observable variables. While numerous expectations models have been advanced and applied in previous economic studies, little is known about how producers actually formulate their expectations. Here, price expectations are of the "quasi-rational" form suggested by Nerlove (1983) and whose validity for beef cattle has been indicated by the work of Bessler. The expectations functions are first- and second-order weighted averages of previous prices. This form is applied to both feeder and slaughter cattle prices:

$$P^e_{tq} = aP_{tq} + (1-a)P_{tq-i} \quad (25)$$

where a = coefficient of expectations,

P_{tq} = observed price in year t, quarter q,

P_{tq-1} = observed price lagged one quarter.

These functions are substituted into their respective equations to eliminate the unobservable expectations variables.

EMPIRICAL MODEL AND ANALYSIS

The economic model developed in the previous section leads to a system of equations determining values for the endogenous variables. The model is static because it specifies that all variables will adjust to equilibrium levels within the period of observation (one quarter). However, observation and past analyses indicate that producers and consumers make gradual adjustments to equilibrium. Respecification to allow for dynamic adjustment permits the static form of the model's equations to be treated as testable hypotheses against the alternative that dynamic adjustment does occur.

Partial Adjustment Model

The partial adjustment model formulated by Nerlove (1958) provides an explanation of economic agents' reaction to changes in exogenous variables. The model predicts that only partial adjustments towards new equilibrium levels are made in any given time period. Partial adjustments lead to differences between short-run and long-run equilibrium levels. The general form of a partial adjustment model for demand or supply comprises two functions, a long-run demand or supply function:

$$Y^*_{tq} = bZ_{tq}, \qquad (25)$$

where Y^*_{tq} is the long-run equilibrium value of the endogenous variable, and Z_{tq} is a vector of endogenous and exogenous explanatory variables. The accompanying partial adjustment function is:

$$Y_{tq} - Y_{tq-1} = h(Y^*_{tq} - Y_{tq-1}), \qquad 0 < h \leq 1 \qquad (26)$$

where h is the partial adjustment parameter. Period-to-period changes in Y are restricted by the parameter h. However, if h equals one the restriction is not binding and the model is, in fact, static.

In empirical work observations of the long-run equilibrium value Y^*_{tq} can not be distinguished from observations of short-run values of Y_{tq}. Combining equations (25) and (26) yields the estimating form of the partial adjustment model:

$$Y_{tq} = hbZ_{tq} + (1-h)Y_{tq-1}. \qquad (27)$$

Respecifying the beef cattle industry in dynamic, estimable form therefore requires simply the addition of lagged endogenous variables to those functions where partial adjustment might occur. Performing this respecifiction, replacing expected prices with their observable equivalents, and inverting demand functions to normalize the model transform it into a set of equations from which its parameters can be estimated by econometric techniques.

Statistical Model

The statistical model is a linear, dynamic, and stochastic version of the underlying economic relationships presented in the previous sections. The overall model contains 1 annual structural equation, 15 quarterly structural equations and 9 identities in quarterly variables, with short-run equilibrium established simultaneously in the 3 market subsectors. The 15 structural equations are specified as being linear in their parameters. Disturbances are assumed to be homoscedastic with zero expected values and no serial correlation. However, contemporaneous correlation among equation disturbances is not ruled out.

Estimation Method and Data

Sufficient numbers of restrictions exist in the model's specification to permit estimation of its parameters. In fact, the model is overidentified. In such case, and given that disturbances may be contemporaneously correlated, three-stage least squares regression analysis is an appropriate estimation technique. It was used to estimate the model.

Data used to estimate the model were primarily from USDA sources. Some data for exogenous variables originating outside the agriculture sector, e.g. the consumer price index, were obtained from U. S. Department of Labor sources. All prices at farm and retail levels are deflated by the consumer price index (CPI, 1967 = 100). The data were quarterly observations from 1965 to 1983, for a total of 76 observations. Variables were classified as: 1) endogenous variables, which are generated within the model; 2) lagged endogenous variables, which are also determined within the model, but at a previous time period; and 3) exogenous variables, which are determined outside the model.

EMPIRICAL RESULTS AND STRUCTURAL ANALYSIS

Parameter estimates for the model and their standard errors are presented in Tables 2, 3 , and 4. In determining significance levels, decision rules applicable to large-size, asymptotic distributions are applied since sampling distributions for three-stage least squares regression estimates are unknown. Thus, coefficients are judged to be significantly different from zero if their absolute values exceed their standard errors.

Signs of significant parameter estimates are generally in accord with theoretical expectations. Exceptions are the negative cross-price coefficients between fed beef and chicken prices and between nonfed beef and pork prices. Detailed discussion of the results and their interpretation are presented in Bedingar (pp. 111-131). Partial adjustment coefficients estimates (one minus corresponding parameter estimates from Tables 2-4) are presented in Table 5, together with corresponding standard errors. All coefficient estimates are different from 1.0, indicating that dynamic adjustment processes are important in the beef cattle industry.

Table 2. U.S. Beef Cattle Industry Model: Feeder Cattle Subsector Parameter Estimates and Standard Errors.

(1) Annual Calf Crop: OLS: $R_2 = 0.94$

$$YCC_t^{a,b} = \underset{(3135.0220)}{7731.9020} + \underset{(0.0638)}{0.6790}\, XBD_{t-1} + \underset{(43.0281)}{47.5618}\, YP1_{t-1} + \underset{(20.4612)}{65.6422}\, XFO_{t-1}$$

$$- \underset{(5.5566)}{32.0054}\, XPF_{t-1}$$

(2) Quarterly Calf Crop: Prior estimates of seasonal percentages

$$YCC_{tq} = d_q\, YCC_t, \quad d_q = (.270, .435, .148, .147)$$

(3) Beef Heifer Replacements: 3SLS

$$YBH_{tq} = \underset{(353.9408)}{-640.7989} + \underset{(3.0858)}{1.0534}\, YP1_{tq} + \underset{(0.0076)}{0.0343}\, YBC_{tq} + \underset{(3.1906)}{8.8600}\, YP1_{tq-4}$$

$$+ \underset{(0.0979)}{0.3391}\, YBH_{tq-1} + \underset{(3.2151)}{6.1788}\, XRC_{tq} + \underset{(89.5695)}{757.6976}\, S_2 - \underset{(191.7771)}{1442.6750}\, S_3$$

$$- \underset{(51.4914)}{758.7720}\, S_4$$

(4) Beef Cow Inventories: 3SLS

$$YBC_{tq} = \underset{(707.912)}{70.5610} + \underset{(22.2059)}{56.1226}\, YP1_{tq} - \underset{(46.8076)}{102.1332}\, YP2_{tq} + \underset{(0.1724)}{0.7887}\, YBH_{tq}$$

$$+ \underset{(5.1516)}{28.8281}\, YP1_{tq-4} + \underset{(0.0120)}{0.9449}\, YBC_{tq-1} - \underset{(1.5661)}{1.7559}\, XCA_{tq} + \underset{(4.7968)}{11.5572}\, XRC_{tq-1}$$

$$+ \underset{(199.2838)}{314.8820}\, S_2 - \underset{(176.1488)}{167.8051}\, S_3 - \underset{(166.4668)}{429.4668}\, S_4$$

Table 2. Continued

(5) Feeder Cattle Imports: 3SLS

$$YFM_{tq} = \underset{(85.8420)}{64.2304} + \underset{(2.9431)}{4.9474}\, YP3_{tq} + \underset{(0.1008)}{0.4112}\, YFM_{tq-1} - \underset{(38.5965)}{66.1311}\, XPC_{tq}$$

$$- \underset{(0.3505)}{0.1725}\, XUV_{tq} + \underset{(35.6551)}{53.6483}\, S_2 - \underset{(32.0468)}{68.9274}\, S_3 + \underset{(36.4596)}{237.6798}\, S_4$$

(6) Feedlot Placements: 3SLS

$$YFP_{tq} = \underset{(1549.6960)}{2672.6650} + \underset{(74.7556)}{229.2965}\, YP1_{tq} - \underset{(144.1999)}{265.67972}\, YP2_{tq} + \underset{(0.1241)}{0.0401}\, YFI_{tq}$$

$$+ \underset{(0.1241)}{0.2156}\, YFP_{tq-1} - \underset{(71.9153)}{172.3794}\, YP2_{tq-1} + \underset{(33.6733)}{11.4352}\, XIR_{tq} + \underset{(455.4468)}{484.3721}\, S_2$$

$$+ \underset{(393.4810)}{1245.1880}\, S_3 + \underset{(366.4385)}{3285.959}\, S_4$$

(7) Feeder Cattle Price: 3SLS

$$YP1_{tq} = \underset{(1.9181)}{-13.5845} + \underset{(0.0822)}{1.5408}\, YP3_{tq} - \underset{(0.00012)}{0.000066}\, YFP_{tq} + \underset{(0.0790)}{0.3321}\, YP3_{tq-1}$$

$$+ \underset{(0.00011)}{0.00030}\, YFP_{tq-1} - \underset{(0.5872)}{4.7595}\, XPC_{tq} - \underset{(0.0657)}{0.0855}\, XIR_{tq}$$

---

[a]Time designations: t = year; tq = current year, quarter; t-1 = lagged one year; tq-1 = lagged one quarter.

[b]Variable definitions: YCC = calf crop, 1,000 head; YP1 = deflated feeder cattle price, \$ per 100 lb; YBH = end-of-period replacement beef heifer inventory, 1,000 head; YBC = end-of-period beef cow inventory, 1,000 head; YP2 = deflated nonfed slaughter cattle price, \$ per 100 lb.; YFM = feeder cattle imports, 1,000 head; YP3 =

Table 2. Continued

deflated fed slaughter cattle price, $ per 100 lb; YFP = feedlot placements, 1,000 head; YFI = end-of-period feeder cattle inventory, 1,000 head; XBD = beef and dairy cow inventory, 1,000 head; XFO = forage output index, 1967=100; XPF = deflated feed price index, 1967=100; XRC = range and pasture condition index, 1967=100; XCA = cropland acreage, 1,000,000 acres; XPC = deflated corn price, $ per bushel; XUV = deflated unit value of feeder cattle imports; XIR = interest rate; S_2, S_3, S_4 = seasonal dummy variables.

Table 3. U.S. Beef Cattle Industry Model: Slaughter Cattle Subsector Subsector Parameter Estimates and Standard Errors.

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(8) Fed Slaughter Cattle Supply: 3SLS

$$YSF_{tq}^{a,b} = \underset{(550.7582)}{2544.4200} - \underset{(21.9315)}{54.2187}\, YP3_{tq} + \underset{(0.0342)}{0.2111}\, YCF_{tq} + \underset{(0.0714)}{0.4006}\, YSF_{tq-1}$$

$$+ \underset{(20.3708)}{22.5826}\, YP3_{tq-1} - \underset{(144.6915)}{181.9554}\, XPC_{tq} - \underset{(16.3741)}{22.1720}\, XIR_{tq}$$

(9) Fed Cattle Price: 3SLS

$$YP3_{tq} = \underset{(1.6959)}{3.0141} - \underset{(0.00018)}{0.00046}\, YSF_{tq} + \underset{(0.0378)}{0.9235}\, YP2_{tq} + \underset{(1.6782)}{11.4557}\, YP4_{tq}$$

$$+ \underset{(0.00016)}{0.00025}\, YSF_{tq-1} - \underset{(0.0367)}{0.0752}\, XIR_{tq} - \underset{(0.4614)}{0.5457}\, XWR_{tq}$$

(10) Nonfed Slaughter Cattle Supply: 3SLS

$$YSN_{tq} = \underset{(540.8088}{932.9412} - \underset{(17.6298)}{51.7783}\, YP2_{tq} + \underset{(0.0216)}{0.0705}\, YFI_{tq} - \underset{(0.0210)}{0.0549}\, YBC_{tq}$$

$$+ \underset{(18.1222)}{4.7248}\, YP2_{tq-1} + \underset{(0.0478)}{0.6138}\, YSN_{tq-1} - \underset{(2.9314)}{1.6317}\, XRC_{tq} + \underset{(102.7215)}{466.4452}\, XPC_{tq}$$

$$- \underset{(0.0210)}{0.0549}\, XDC_{tq} - \underset{(141.7861)}{7.2646}\, S_2 + \underset{(93.3014)}{499.0676}\, S_3 + \underset{(88.3837)}{661.1579}\, S_4$$

(11) Nonfed Cattle Price: 3SLS

$$YP2_{tq} = \underset{(1.4252)}{-2.9627} - \underset{(0.00019)}{0.00175}\, YSN_{tq} + \underset{(0.0478)}{0.7254}\, YP3_{tq} + \underset{(2.2158)}{2.5291}\, YP5_{tq}$$

$$+ \underset{(0.00020)}{0.00126}\, YSN_{tq-1} - \underset{(0.0376)}{0.0279}\, XIR_{tq} + \underset{(0.3781)}{0.3941}\, XWR_{tq} + \underset{(0.2081)}{0.7958}\, S_2$$

$$+ \underset{(0.2413)}{1.0207}\, S_3 + \underset{(0.2281)}{0.4563}\, S_4$$

Table 3. Continued.

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[a]Time designations: t = year; tq = current year, quarter; t-1 = lagged one year; tq-1 = lagged one quarter.

[b]Variables Definitions: YSF = fed cattle slaughter, 1,000 head; YCF = end-of-period cattle on feed, 1,000 head; YSN = nonfed cattle slaughter, 1,000 head; YFI = end-of-period feeder cattle inventory, 1,000 head; YBC = end-of-period beef cow inventory, 1,000 head; YP2 = deflated nonfed slaughter cattle price, $ per 100 lb.; YP3 = deflated fed slaughter cattle price, $ per 100 lb.; YP4 = deflated retail, fed beef price, $ per lb; YP5 = deflated retail, nonfed beef price, $ per lb; XPC = deflated corn price, $ per bu.; XIR = interest rate; XWR = deflated meatpacking wage rate; XRC = index of pasture and range condition; XDC = end-of-period dairy cow inventory, 1,000 head; S_{2-4} = seasonal dummy variables.

Table 4. U.S. Beef Cattle Industry Model: Wholesale-Retail Beef Market Subsector: Parameter Estimates and Standard Errors.

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(12) Per Capita Fed Beef Supply: 3SLS

$$YSC_{tq}^{a,b} = \underset{(1.1884)}{-1.6905} + \underset{(0.00018)}{0.00222}\ YSF_{tq} + \underset{(0.0253)}{0.1105}\ YP3_{tq-1} + \underset{(0.0620)}{0.2204}\ YSC_{tq-1}$$

$$- \underset{(0.02911)}{0.02911}\ XCG_{tq}$$

(13) Fed Beef Price: 3SLS

$$YP4_{tq} = \underset{(0.0416)}{0.3049} - \underset{(0.00274)}{0.00649}\ YSC_{tq} + \underset{(0.0723)}{0.8322}\ YP5_{tq} + \underset{(0.00163)}{0.00072}\ YSC_{tq-1}$$

$$+ \underset{(0.0614)}{0.1314}\ XPP_{tq} - \underset{(0.0745)}{0.1678}\ XPB_{tq} + \underset{(0.00272)}{0.00548}\ XME_{tq}$$

(14) Per Capita Domestic Nonfed Beef Supply: 3SLS

$$YSD_{tq} = - \underset{(0.6712)}{0.9712} + \underset{(0.00011)}{0.00209}\ YSN_{tq} + \underset{(0.0169)}{0.0265}\ YP2_{tq} + \underset{(0.0412)}{0.2388}\ YSD_{tq-1}$$

$$+ \underset{(0.0060)}{0.0062}\ XRC_{tq} + \underset{(0.1066)}{0.3857}\ S_2 + \underset{(0.1532)}{0.4991}\ S_3 + \underset{(0.1460)}{0.4259}\ S_4$$

(15) Per Capita Beef Imports: 3SLS

$$YBM_{tq} = \underset{(0.5660)}{0.7817} - \underset{(0.0224)}{0.0079}\ YSD_{tq} + \underset{(0.6393)}{0.7404}\ YP5_{tq} + \underset{(0.0969)}{0.1727}\ YBM_{tq-1}$$

$$+ \underset{(0.1861)}{0.4428}\ XIQ_{tq} - \underset{(0.0170)}{0.361}\ XIR_{tq} + \underset{(0.1066)}{0.0328}\ S_2 + \underset{(0.1095)}{0.3235}\ S_3$$

$$- \underset{(0.1191)}{0.0247}\ S_4$$

Table 4. Continued.

(16) Nonfed Beef Price: 3SLS

$$YP5_{tq} = -\underset{(0.0463)}{0.1484} - \underset{(0.0019)}{0.0058}\ YSH_{tq} + \underset{(0.0614)}{0.7140}\ YP4_{tq} - \underset{(0.0015)}{0.0020}\ YSH_{tq-1}$$

$$- \underset{(0.0570)}{0.1575}\ XPP_{tq} + \underset{(0.0962)}{0.1733}\ XPB_{tq} + \underset{(0.00149)}{0.00456}\ XME_{tq} + \underset{(0.0012)}{0.0014}\ XAF_{tq}$$

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[a]Time designations: t = year; tq = current year, quarter; t-1 = lagged one year; tq-1 = lagged one quarter.

[b]Variable definitions: YSC = quantity of fed beef, lbs. carcass weight equivalent per capita; YSF = fed cattle slaughter, 1,000 head; YSD = domestic nonfed beef supplied, lb. carcass weight equivalent per capita; YSN = nonfed cattle slaughter, 1,000 head; YBM = beef imports, lb. carcass weight equivalent per capita; YSH = total quantity of nonfed beef, lb. carcass weight equivalent per capita; YP2 = deflated nonfed slaughter cattle price, $ per 100 lb.; YP3 = deflated fed slaughter cattle price, $ per 100 lb.; YP4 = deflated retail fed beef price, $ per lb.: YP5 = deflated retail nonfed beef price, $ per lb.; XCG = deflated feeding cost per 100 lb. of gain; XPP = deflated retail price of pork, $ per lb.; XPB = deflated retail price of chicken, $ per lb.; XME = deflated consumer expenditures on red meats and poultry, $ per capita; XRC = index of range and pasture condition; XIQ = annual beef import quota/ 4, lb. carcass weight equivalent per capita; XIR = interest rate; XAF = deflated away-from-home food expenditures, $ per capita; S_{2-4} = seasonal dummy variables.

Table 5. Dynamic Adjustment Coefficients.

Variable	Coefficient	Standard Error
Replacement Heifers (YBH)	.6609	.0979
Beef Cow Inventory (YBC)	.0551	.0120
Feeder Cattle Imports (YFM)	.5888	.1008
Feedlot Placements (YFP)	.7844	.1241
Fed Slaughter Cattle (YSF)	.5994	.0714
Nonfed Slaughter Cattle (YSN)	.3862	.0478
Fed Beef Supply (YSC)	.7196	.0620
Domestic Nonfed Beef Supply (YSD)	.7612	.0412
Beef Imports (YBM)	.8273	.0969

Model Validation

Due to its structure, Gauss-Seidel simulation methods are required to predict values of the endogenous variables from the model. General procedures for Gauss-Seidel simulations are shown in Labys and Pollak (p. 56). Predictions for all endogenous variables were made for the 1965-83 sample period in order to evaluate the goodness-of-fit of the model. Root mean square percentage errors provide a measure of the deviation of predicted from observed values of variables in a form convenient for comparisons between variables. Root mean square percentage errors are shown for all quarterly endogenous variables in Table 6. The largest error is 92.4 percent, for feeder cattle imports. The next highest is for beef imports, at 21.3 percent. Root mean square percentage errors for all other variables are less than 15 percent. By comparison, the dynamic version of Arzac and Wilkinson's quarterly model yielded prediction errors of 20.5 percent for feeder cattle price, 11.8 percent for fed beef price, and 17.2 percent for nonfed beef price.

Table 6 also displays statistics relating to the source of prediction errors. Prediction errors are systematic or unsystematic, depending on whether they can be attributed to errors in predicting the mean of the variable (unequal mean), its variance (unequal variance), or unequal covariation. The first two of these are systematic errors and indicate faults in the structure. The third is unsystematic or random prediction error (Theil). Predictions of per capita beef imports display the largest systematic errors for both expected value and expected variance. Expected variance error is also

Table 6. Goodness-of-Fit

Statistics for the Beef Cattle Industry Model

Variable	RMSPE[a]	Sources of Error		
		Unequal Mean	Unequal Variance	Unequal Covariation
	.... percent			
Feeder Cattle Inv. (YFI)	1.4	--[b]	--	1.4
Beef Heifers (YBH)	11.7	--	0.3	11.4
Beef Cows (YBC)	0.9	--	0.1	.8
Feeder Imports (YFM)	92.4	0.1	7.0	85.3
Feeder Supply (YFS)	12.7	--	3.0	9.7
Feeder Price (YP1)	15.0	0.1	0.1	14.7
Cattle on Feed (YCF)	12.9	0.1	0.1	12.7
Fed Cattle Supply (YSF)	9.0	0	0.5	8.6
Nonfed Cattle Supply (YSN)	9.4	--	0.5	8.9
Fed Cattle Price (YP3)	9.0	0.1	0.2	8.7
Nonfed Cattle Price (YP2)	12.3	0.1	0.2	11.9
Fed Beef Supply (YSC)	7.9	0	0.1	7.8
Domestic Nonfed Beef (YSD)	10.0	0	0.5	9.6
Beef Imports (YBM)	21.3	4.7	5.7	10.8
Total Nonfed Supply (YSH)	7.0	0.6	0.1	6.3
Fed Beef Price (YP4)	4.4	0.1	--	4.3
Nonfed Beef Price (YP5)	5.9	0.5	0	5.5

[a]RMSPE is root mean square percentage error.

[b]Less than 0.5 percent. Totals may not add to RMSPE due to rounding.

comparatively large for feeder cattle supply to feedlots. For all other variables systematic error is ten percent or less of total prediction error. This includes feeder cattle imports. Thus, while the model does not predict feeder cattle imports very well, most of the error is randomly distributed. Prediction bias is relatively small. In future work perhaps other exogenous variables could be found to improve predictive performance for feeder imports. On the other hand, structural bias is comparatively large for beef imports. This suggests that respecification within the present structure is needed for beef imports.

Structural Elasticities and Price Flexibilities

Elasticity and price flexibility coefficients are convenient ways of expressing relationships among variables and are comparable with similar measures from other models. Elasticities and flexibilities are measured at sample period means for relationships among endogenous variables and between endogenous and exogenous variables. Both short and long-run relationships are calculated. Table 7 shows short-run price elasticities of demand and supply for selected quantity variables. Neither beef cow nor heifer inventories are very sensitive to prices. It is difficult to evaluate the multiple price relationships for beef cow inventories and feeder cattle supply to feedlots, because these prices do not in fact change indpendently of one another. However, the net effect of an increase in prices is to increase beef cow numbers and to increase the flow of feeder cattle to feedlots. The negative price elasticity of supply of livestock for slaughter is a well-known phenomena in the beef industry

Table 7. Short-Run Price Elasticities at Sample Period Means for Selected Endogenous Variables

Dependent Variable	Prices for Feeder Cattle	Fed Cattle	Nonfed Cattle	Fed Beef	Nonfed Beef
Beef Heifers (YBH)	.017				
Beef Cows (YBC)	.039		-.044		
Feeder Imports (YFM)		.498			
Feeder Supply (YFS)	1.047		-.743		
Fed Cattle Supply (YSF)		-.227			
Nonfed Cattle Supply (YSN)			-.295		
Fed Beef Supply (YSC)		.156			
Domestic Nonfed Beef Supply (YSD)			.052		
Beef Imports (YBM)					.201
Feeder Cattle Price (YP1)		1.379			
Nonfed Cattle Price (YP2)		1.085			.086
Fed Cattle Price (YP3)			.617	.414	
Fed Beef Price (YP4)					.520
Nonfed Beef Price (YP5)				1.142	

and is documented elsewhere (Nelson and Spreen). The paradox which it seems to present is resolved by the beef supply elasticity, which is conventionally positive. These relationships show the usefulness of separate supply functions for slaughter cattle and for beef. The interactions between lengths of feeding periods and slaughter weights really can not be resolved in single supply functions.

The largest cross-price elasticity is between feeder cattle prices and fed cattle prices. This elasticity is consistent with differences in variability between these price series. Even after deflation the standard deviation of feeder cattle price ($7.27 per hundredweight) is nearly twice that of fed cattle ($3.90 per hundredweight). The cross-price elasticity between fed and nonfed slaughter cattle is nearly unitary, and the response of nonfed beef price to fed beef price is greater than one. Otherwise, the cross-price responses are less than one.

Long-run price elasticities of supply are shown in Table 8. They differ from the short-run estimates according to the degree of partial adjustment estimated. Heifer and beef cow inventories are considerably more price responsive in the long run. This is in keeping with the biological and investment relationships involved. The increase in the nonfed slaughter cattle supply elasticity from short- to long-run is considerably larger than for fed cattle. This reflects the fact that increases in beef cow inventories reduce numbers of cows slaughtered. Cross-price elasticities are the same as in the short run, because no partial adjustments were specified in the price functions.

Table 8. Long-Run Price Elasticities at Sample Period Means for Selected Endogenous Variables

Dependent Variable	Prices for Feeder Cattle	Prices for Fed Cattle	Prices for Nonfed Cattle	Prices for Fed Beef	Prices for Nonfed Beef
Beef Heifers (YBH)	.026				
Beef Cows (YBC)	.714		-.796		
Feeder Imports (YFM)		.846			
Feeder Supply (YFS)	1.334		-.947		
Fed Cattle Supply (YSF)		-.373			
Nonfed Cattle Supply (YSN)			-.763		
Fed Beef Supply (YSC)		.200			
Domestic Nonfed Beef Supply (YSD)			.068		
Beef Imports (YBM)					.243
Feeder Cattle Price (YP1)		1.379			
Nonfed Cattle Price (YP2)		1.085			.086
Fed Cattle Price (YP3)			.617	.414	
Fed Beef Price (YP4)					.520
Nonfed Beef Price (YP5)				1.142	

Short-run elasticities and flexibilities with respect to selected exogenous variables are shown in Table 9. Most coefficients are comparatively small, indicating a generally low responsiveness of the beef cattle industry to exogenous influences. The indicated responses to changes in range and pasture conditions are of this nature. The tendency to liquidate herds under drouth conditions is captured in the elasticity of nonfed slaughter with respect to range condition. Responses to feed prices are interesting, especially the opposite signs for the supplies of fed and nonfed slaughter cattle. Corn price increases cause slaughter cattle marketings to shift from fed to nonfed status. Similar sign shifts were found by Ospina and Shumway between choice and good beef supply. Per capita fed beef supply is also reduced as slaughter weights adjust. Negative elasticities for feeder imports and prices show the inverse influence of feed price on feeder cattle demand.

Small but logical responses to changes in the opportunity costs of holding cattle inventories are reflected in responses to interest rates. Prices of both feeder and fed slaughter cattle are reduced by rising interest rates. Both fed and nonfed beef prices respond positively to increases in per capita meat expenditures. It must be stressed that these are price flexibilities rather than income elasticies of demand.

Cropland acreage and dairy cow inventories are also significant exogenous variables in the model and have interesting policy implications. However, these implications have been explored in related publications (Bobst and Davis, 1987; Bedingar and Bobst) and

Table 9. Short-Run Elasticities and Price Flexibilities at Sample Means for Selected Exogenous Variables.

		Exogenous Variable		
Endogenous Variable	Range Condition	Feed Price	Interest Rate	Meat Expenditures
Beef Heifers (YBH)	.291			
Beef Cows (YBC)	.023			
Feeder Imports (YFM)		-.316[a]		
Feeder Supply (YFS)			.018	
Feeder Price (YP1)		-.207[a]		
Fed Cattle Supply (YSF)		-.036[a]	-.034	
Fed Cattle Price (YP3)			-.028	
Nonfed Cattle Supply (YSN)	-.043	.187[a]		
Fed Beef Supply (YSC)		-.043[b]		
Fed Beef Price (YP4)				.216
Nonfed Beef Price (YP5)				.288

[a] Corn price

[b] Feeding cost per 100 pounds of gain

so are not discussed further here.

CONCLUSIONS

The most general conclusion is that the model's estimated relationships appear consistent with the workings of the U.S. beef cattle industry. Most parameters are plausible, and, with the exception of imports, predictive capabilities seem satisfactory. All partial adjustment coefficient estimates are less than one, indicating that the model is dynamically stable. This is a necessary condition for the model to be able to reproduce the fluctuations (possibly cyclical) of the industry over time.

Predictive performances support the specification of short-run equilibrium being determined simultaneously at several different market levels. The simultaneous determination of prices for feeder cattle, slaughter cattle, and for beef is a major contribution to knowledge about the industry's functioning. No known previous study has attempted to estimate all three levels together. The feeder cattle price function in particular should be very useful in livestock analysis in Kentucky because of the importance of feeder cattle production in Kentucky agriculture.

Elasticity results indicate that the beef cattle industry is generally price inelastic. This conclusion agrees with the findings of most previous research. All supply equations are price inelastic with the exception of feeder cattle supply to feedlots. This supply function is elastic with respect to feeder cattle prices in the short run (1.05) and in the long run (1.33). Negative price elasticities of supply for fed and nonfed slaughter cattle have already been discussed. However, they are a key to understanding the complexities of livestock markets and the interplay between meat and live animal price determination.

Although own-price flexibilities of demand are not shown in the tables, the negative signs of their parameters indicate that they are negative at all market levels, as theory suggests. Theory also suggests that price flexibilities of demand with respect to meat expenditures be positive, if fed and nonfed beef are normal goods with positive income elasticities. They are positive, contrary to previous studies that seemed to indicate that nonfed beef was an inferior good (Langemeier and Thompson; Freebairn and Rausser; and Ospina and Shumway for good beef).

Responses to exogenous variables all appear to be inelastic, suggesting that the beef cattle industry is relatively insensitive to changes in input prices and input quantities. In fact, the industry is quite stable in many respects. Coefficients of variation for per capita consumption of fed and nonfed beef were 10.8% and 20.5% respectively during the sample period. Coefficients of variation for their retail prices were 8.5% and 13.3% respectively. At the other end of the industry, the coefficient of variation for beef cow inventories were 8.9%. Endogenous relationships seem to be responsible for much of the variation in such variables as feeder cattle prices (coefficient of variation = 26.6%). Such relationships seem to be estimated with a greater degree of predictive performance than obtained in most previous studies. Therefore, the model should be quite useful in evaluating the effects of agricultural policy changes on the beef cattle industry. Also, given reliable estimates of its exogenous variables, the model should be quite useful in forecasting.

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APPENDIX

Table 1. Means and Standard Deviations of Quarterly Endogenous Variables, 1965-1983.

Variable Name (Symbol)	Mean	Std. Deviation
A. Cattle Numbers	.... 1,000 head.............	
Quarterly Calf Crop (YCC)	73.9	5.6
Beef Heifers (YBH)	1658.2	832.4
Beef Cows (YBC)	39025.4	3476.5
Feeder Imports (YFM)	248.7	129.4
Feedlot Placements (YFP = YFS)	6012.2	1370.1
Feeder Cattle Inventory (YFI)	44483.4	4793.0
Cattle on Feed (YCF)	11021.0	1572.9
Fed Cattle Slaughter (YDF = YSF)	6055.0	660.6
Nonfed Cattle Slaughter (YDN = YSN)	2963.4	864.4
B. Per Capita Quantities	... pounds carcass weight ...	
Fed Beef (YDC = YSC)	17.72	1.91
Domestic Nonfed Beef Supply (YSD)	8.58	2.29
Beef Imports (YBM)	2.08	0.47
Total Nonfed Beef (YDH = YSH)	10.66	2.18
C. Deflated Prices	..... $ per pound	
Feeder Cattle (YP1)	.2732	.0727
Nonfed Slaughter Cattle (YP2)	.1673	.0347
Fed Slaughter Cattle (YP3)	.2503	.0390
Retail Fed Beef Price (YP4)	.9057	.0773
Retail Nonfed Beef Price (YP5)	.5661	.0751

Table 2. Means and Standard Deviations of Quarterly Exogenous Variables, 1965-1983.

Variable Name and Symbol[a]	Unit	Mean	Standard Deviation
Cropland Acreage (XCA)	mill ac.	354.7	20.0
Pasture Condition Index (XRC)	1967=100	78.2	5.5
Corn Price (XPC)	$/bu.	1.19	.29
Interest Rate (XIR)	%/yr.	9.2	2.5
Import Unit Value (XUV)	$/hd.	115.29	37.74
Calf Slaughter (XCS)	thou. hd.	1061.6	405.1
Death Loss (XDL)	thou. hd.	1029.3	314.5
Nonfed Steer & Heifer Slaughter (XNS)	thou. hd.	864.7	448.4
Dairy Cow Invent. (XDC)	thou. hd.	13166.6	1650.9
Dairy Heifers (XDR)	thou. hd.	1030.3	496.2
Meatpacking Wage Rates (XWR)	$/hr.	3.36	.21
Feeding Cost (XCG)	$/100 lbs. gain	26.10	5.02
Retail Pork Price (XPP)	$/ lb.	.68	.09
Retail Chicken Price (XBP)	$/ lb.	.35	.06
Meat Expenditures (XME)	$/capita	36.77	3.48
Away-from-Home Food (XAF)	% food exp.	20.3	2.8

[a]Prices and income variables deflated by the CPI, 1967 = 100.

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