Disaggregated Analysis of Short-run Beef Supply Response

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Conceptual problems in model specification of beef supply response studies are investigated and a simultaneous equation model is formulated to estimate annual U.S. carcass supply, demand, and inventories of beef. Three basic issues are addressed: (a) disaggregation, (b) simultaneity, and (c) differentiation between current and expected price effects. Empirical results indicate positive supply response of each quality type of steers and heifers, and negative supply response of cows to current own-price changes. The derived aggregate supply elasticity is positive. The effects of grain price changes on beef price, supply and composition are also evaluated.

Nelson and Spreen recently refocused attention on the controversy surrounding proper specification of the short run supply relationship for slaughter cattle. A variety of models have been developed and fitted resulting frequently in zero or negative elasticities of supply with respect to cattle prices.[1] The variability in short run slaughter supply elasticities derived with different models is great, varying both with the time interval defined as short run and with model specification. Among annual models these elasticities range from −.17 [Reutlinger] to +.16 [Langemeier and Thompson] for all beef, from 0 [Freebairn and Rausser] to +.23 [Langemeier and Thompson] for fed beef, and from −.97 [Shuib and Menkhaus] to +.61 [Freebairn and Rausser] for non-fed beef. Supply elasticity estimates with respect to feed prices also have been unstable. These findings, a product of nearly two additional decades of econometric modeling, further validate Knight's 1961 observation that "research workers have probably had more difficulty deriving meaningful and realistic supply-price elasticities for beef than for any of the other commodities" (p. 82).

The frequently estimated negative supply elasticities seem contrary on the surface to economic reasoning for a marketed commodity. Explanation has been sought in the fact that cattle are both consumption goods and capital goods. Slaughter and inventory decisions are made simultaneously [Reutlinger; Jarvis; Nelson and Spreen]. Further, because gestation lasts 9 months and cows typically bear only one offspring at a time, the ratio of breeding herd inventory to animal slaughter is large and much greater than for either hogs or poultry. Consequently, it is reasoned that the difference between current and expected future prices should be extremely important in explaining current cattle slaughter [Elam; Nelson and Spreen].

Further, beef is a heterogeneous product consisting of carcasses from steers, heifers, and culled members of the breeding herd.

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[1]A zero elasticity is typically the result of deleting the price variable prior to final estimation of the beef supply equation because the initial parameter estimate was negative, not significant, or both.

Carcass quality for consumption varies substantially depending on age and production practices employed. It is reasoned that the class and quality composition of carcass beef undoubtedly changes in response to price changes. This expectation has been documented previously in the form of supply response differences between fed and non-fed beef [Langemeier and Thompson; Freebairn and Rausser] and between steers, heifers, and cows [Reutlinger].

Objectives

The model specified here incorporates these three important conceptual issues plus simultaneity in supply and demand for beef. In addition, carcass beef is disaggregated into more homogeneous groupings than in prior studies with the goal of generating more reliable estimates of supply responsiveness both of beef components and of the entire beef industry. The specific objectives of this study are (a) to formulate a disaggregated, annual, simultaneous equation model of the U.S. livestock sector that differentiates between current and expected price effects in order to estimate beef supply, demand, and inventory response (b) to obtain elasticity estimates for the components and for the aggregate, and (c) to assess the impact of feed price changes on beef prices, supply and composition. The period of analysis is 1956-1975.

Economic Model

Carcass beef is disaggregated into steer, heifer, and breeding herd cull classes.[2] Instead of disaggregating by quality into fed and non-fed beef components as in previous studies, USDA grade standards are used to define three quality categories: choice-prime (choice), good, standard and lower (utility). Three basic explanatory relationships are specified from neoclassical theory: carcass slaughter supplies are defined as functions of current prices, inventories as functions of expected prices, and carcass demand as functions of current prices and income. Demand, supply, and inventories are simultaneously determined within the model.

Competition in the use of resources, mainly feed grains, and in consumption warrant the incorporation of hog and broiler subsector decisions in the model. Feed grain supplies are considered predetermined outside the beef industry in the short run. Linear functions are specified to explain: (a) slaughter supply of two defined quality categories (choice and good) of steers and of heifers; (b) supply of slaughter cows, beef imports, pork, and broilers; (c) feeder cattle inventory formation; (d) breeding herd inventory formation for beef and pork; and (e) demand for pork, broilers and three defined types of beef (choice, good, and utility).

Steer Supply

Slaughter steers are a primary product of the beef industry. Total slaughter is determined by number of animals slaughtered and their average weight. Although number of animals slaughtered within a year is largely predetermined by prior decisions governing size of the breeding herd, weight per animal can be affected by length of feeding and so is expected to be related to current prices. For any quality type, supply of slaughter steers (in total weight) during the year is specified as a function of current product and variable input prices and fixed input level (i.e., inventories). In linear form, this relationship is:

$$(1)\quad SS_t = a_{10} + a_{11}PS_t + a_{12}PA_t + a_{13}PCN_t + a_{14}IFC_t$$

where SS_t is current steer slaughter in weight; PS_t, PA_t, PCN_t are current own-price, closest production alternative (i.e., other quality) price, and major variable input (corn) price,

[2]In the empirical model, bulls and standard grade steers and heifers are included with cow slaughter supply. Although standard grade steer and heifer beef is marketed in quite different ways than cull cow and bull beef, it represents a very small proportion of total beef. Since these animals typically are not fed appreciable amounts of grain, they are grouped in this study with breeding herd culls because of production similarities rather than with good grade steers and heifers. This category is referred to as cow slaughter.

respectively; IFC_t is current January 1 feeder cattle inventory for steers and heifers 500 pounds and over.

From neoclassical theory of the firm, response to own-price changes is expected to be positive. The closest production alternative is defined as the next lower or upper quality category to which production can be switched by simply varying the amount of grain fed; thus, the response to alternative product price is expected to be negative. Choice steer supply is expected to respond negatively to variable input (i.e., corn) price. Good steer supply, on the other hand, is expected to move in the same direction as corn price since an increase in grain price mainly reduces the amount of grain fed per animal rather than the number of animals fed. Fewer steers (and heifers) are fed enough grain to grade choice, but they still grade higher than standard. The quantity of beef slaughtered during the year in each class is expected to be positively related to the number of animals available for slaughter at the beginning of the year (i.e., the fixed input level.) Expected signs are a_{11}, $a_{14}>0$; $a_{12}<0$; $a_{13}<0$ for choice grade; $a_{13}>0$ for the good grade equation.

Feeder Cattle Inventory

Inventories of feeder cattle are a consequence of past adjustments in the breeding herd, number of calves born, number of calves slaughtered, and death losses. Because widespread weather inclemencies and disease are rare, death losses change little from year to year [Ehrich]. However, since the option exists to slaughter young calves for veal, the theory of the firm implies that vealer price, feed input price, expected cattle slaughter price, and competitive enterprise price should be relevant in determining the number of calves that are retained for later slaughter. This functional relationship can be expressed linearly as:

$$(2)\quad IFC_t = a_{20} + a_{21}PSH_t^* + a_{22}PPK_t^* + a_{23}PCN_t^* + a_{24}PV_{t-1} + a_{25}IBH_{t-1}$$

where PSH*, PPK*, PCN* are expected prices for own-product (slaughter steer and heifer), competitive product (pork), and input (corn), respectively; the subscript indicates the expectation is for year t given conditions prevailing in and prior to year $t-1$ when the feeder cattle inventory decision was made; PV is price of vealers and reflects incentive for calf slaughter; IBH_{t-1} is January 1 breeding herd inventory in the prior year and is a measure of the potential supply of feeder cattle. Expected signs are a_{21}, $a_{25}>0$; a_{22}, a_{23}, $a_{24}<0$.

Breeding Herd Inventory

Heifers and cows serve a dual purpose as both capital goods and consumption goods [Reutlinger; Jarvis; Nelson and Spreen]. As a consequence, their slaughter supply equations must take into account current demand for breeding herd inventories.[3] Following Reutlinger (pp. 910-13), the number of heifers and cows slaughtered can be viewed within this context simply as the difference between available heifers and cows in a given year and demand for breeding herd inventory in the same year:

$$(3)\quad N_t \equiv A_t - DIBH_t$$

where N is number of slaughter heifers and cows, A is total available heifers and cows, and DIBH is demand for change in the breeding herd inventory, all in animal numbers. Breeding herd inventory demand is thus treated as a conceptual (although not necessarily temporal) antecedent to cow and heifer slaughter supply. It is defined as the difference in inventories between two subsequent years:

$$(4)\quad DIBH_t \equiv IBH_{t+1} - IBH_t.$$

[3]Both Jarvis and Reutlinger develop models of beef supply that derive slaughter supply equations from inventory demand relationships. While Jarvis' development is more inclusive and also more elegant in demonstrating the logical chain of implication, both models are derivable directly from the neoclassical theory of the firm. Our conceptualization of breeding herd inventory demand and slaughter supply departs from the simpler Reutlinger model.

Identity (4) represents net changes (positive or negative) in inventory numbers which occur by changes in either heifer or cow slaughter.

To explain inventory changes, desired inventories are defined as functions of *expected* prices of output and variable inputs, and fixed input levels. Expected revenue from and costs of producing offspring from these animals thus create the incentive to increase or decrease breeding herd inventory. In linear form this relationship is expressed as:

$$(5)\quad IBH^*_{t+1} = a_{30} + a_{31}PSH^*_{t+2} + a_{32}PCN^*_{t+2} + a_{33}RX^*_{t+1}$$

where IBH* represents desired breeding herd inventory, RX* is expected range conditions representing expected level of the major fixed input to the breeding herd, and the subscript indicates the year of expectation given conditions prevailing in and prior to year $t-1$.[4] Sign expectations are a_{31}, $a_{33}>0$; $a_{32}<0$.

Desired inventory as specified by equation (5) is not an observable variable. However, the difference between actual inventories in years t and t+1 frequently is assumed to be a constant proportion of the difference between actual inventory in year t and desired inventory in year t+1 (Griliches):

$$(6)\quad IBH_{t+1} - IBH_t = c(IBH^*_{t+1} - IBH_t)$$

where $0<c<1$.

Substituting equations (5) and (6) into (4) leads to the expression for inventory demand:

$$(7)\quad DIBH_t = ca_{30} + ca_{31}PSH^*_{t+2} + ca_{32}PCN^*_{t+2} + ca_{33}RX^*_{t+1} - cIBH_t.$$

With the exceptions of the expected range condition variable and inclusion of prices in linear rather than ratio form, this equation is the same as Reutlinger's equation (6).[5]

Heifer Supply

Slaughter heifer supply can now be defined. Available heifers in a given year are a proportion of feeder cattle inventories:

$$(8)\quad AH_t = d_1IFC_t$$

where AH is total available heifers and d_1 is the proportion of heifers in feeder cattle inventory.[6] The value of d_1 is expected to be quite stable near 0.5. Following equation (3) yields:

$$(9)\quad NH_t = d_1IFC_t - d_2IBH_t - d_3DIBH_t$$

where NH is number of slaughter heifers, d_2 is the normal replacement rate, and d_3 is the proportion of breeding herd inventory changes satisfied by modifications in heifer slaughter. For simplicity d_2 and d_3 are assumed constant [Reutlinger, equations (11) and (13)].[7] The first term on the right side of (9) is available heifers; the other two terms together depict heifer demand for the breed-

[4]It takes nearly three years from the time a decision to modify inventories is made before the impact of its offspring on steer and heifer slaughter is realized (Bentley, Waters, and Shumway).

[5]It is also consistent with Tryfos' inventory demand equation. Only two differences exist between our equation and his equation (4): (a) he uses current prices as proxies for expected prices, and (b) we include expected range condition as an independent variable.

[6]If equation (2) were substituted for IFC in (8), we would obtain a relation similar to Reutlinger's equation (10).

[7]Although some heifers in the feeder cattle inventory on January 1 remain in the inventory after December 31, most either enter the breeding herd or are slaughtered during the year. Thus, Reutlinger's term for heifer inventory demand is not included in this equation. Further, Reutlinger's heifer inventory demand is specified as a function of the same variables as number of heifers available (except IBH is unlagged). Since IBH_t and IBH_{t-1} are highly correlated, he dropped IBH_t from his estimation equation. Consequently, our estimation equation does not differ from his in this respect.

ing herd inventory, both for replacement and change in breeding herd size.

Total slaughter supply of heifers is equal to the number of heifers slaughtered multiplied by their average weight. Following the reasoning for equation (1), weight is expected to be related to current prices. Thus, heifer slaughter supply of a given quality type is specified as a function of current own and alternative product prices, variable input price, and the fixed input level (NH):

$$(10) \quad SH_t = a_{40} + a_{41}PH_t + a_{42}PA_t + a_{43}PCN_t + f_1NH_t$$

$$= a_{40} + a_{41}PH_t + a_{42}PA_t + a_{43}PCN_t + a_{44}IFC_t + a_{45}IBH_t + a_{46}DIBH_t$$

where SH is slaughter heifer supply in weight, PH is own-price, and other variables are as previously defined. The last three terms represent the parameter f_1 multiplied by equation (9). Since d_1, d_2, and d_3 are all positive, sign expectations are a_{41}, $a_{44}>0$; a_{42}, a_{45}, $a_{46}<0$; $a_{43}<0$ for choice grade; $a_{43}>0$ for the good grade equation.

This equation differs from Reutlinger's heifer supply equation (15) in that the theoretical effects of current and expected prices are separated. Expected price changes provide incentive to increase or decrease breeding herd inventory while current price changes provide direct incentive to alter slaughter supplies. Only as they might affect expected prices do current prices impact on inventory demand. In contrast to Reutlinger's model, the sign of the own-price variable in the heifer supply equation can be clearly hypothesized *a priori*.

Cow Supply

The supply equation for slaughter cows can be derived similarly. Total available cows in a given year are:

$$(11) \quad ACW_t = d_4IBH_t + d_5IDH_t$$

where ACW is available cows; IDH is a predetermined variable — dairy breeding herd inventory; d_4 and d_5 are normal culling rates for beef and dairy breeding herds, respectively, and are assumed to be constants (with d_4 being d_2 minus breeding herd death rate). Following equation (3), number of slaughter cows is:

$$(12) \quad NCW_t = d_4IBH_t + d_5IDH_t - d_6DIBH_t$$

where d_6 is the proportion of breeding herd inventory demand satisfied by variations in the culling rate (i.e., $1-d_3$). By the same logic as used for equation (10), cow slaughter supply is formulated as:

$$(13) \quad SCW_t = a_{50} + a_{51}PCW_t + f_2NCW_t$$

$$= a_{50} + a_{51}PCW_t + a_{52}IBH_t + a_{53}IDH_t + a_{54}DIBH_t$$

where SCW is cow slaughter in weight and PCW is utility slaughter cow price. Grain and alternative product quality prices are not included in this equation because cull cows typically grade less than standard and are not fed significant quantities of grain prior to slaughter. Because d_4, d_5, and d_6 are positive, expected signs are a_{51}, a_{52}, $a_{53}>0$; $a_{54}<0$.

These equations for slaughter heifers and cows account for simultaneity in inventory formation and slaughter decisions. Inventories are endogenous to the model. Effects of both current and expected prices are recognized and separated. A few previous models [Freebairn and Rausser; Folwell and Shapouri; Tryfos] had endogenously determined inventories. However, Freebairn and Rausser did not include current inventories as explanatory variables in the supply equations, and current prices were deleted from the fed beef supply equations. Neither Folwell and Shapouri nor Tryfos included prices in the supply equations.

Other Relationships

The remaining linear equations will be discussed only in implicit form (for a complete development see Ospina and Shumway 1980). Beef import supply is specified as a function of current U.S. utility grade beef price and dummy variables to account for the impact of the 1964 Meat Import Bill on slope and intercept.

Slaughter pork supply is a function of current pork and corn prices, inventory of breeding sows, and a shift variable — pigs raised per litter [Freebairn and Rausser]. Breeding sow inventory is a function of expected prices for pork, beef and corn, and lagged sow inventories.

Slaughter broiler supply is a function of past broiler and corn prices and a shift variable — labor productivity in the broiler industry. Broiler supplies are not expected to be highly dependent on prior inventories. Less than a year is required between broiler planning decisions and slaughter, and no significant response of supplies to current prices was observed in prior studies [Freebairn and Rausser].

Carcass demand functions for the three quality types of beef (choice, good, and utility), for pork, and for broilers are explained by current own and alternative meat prices, disposable personal income, and the wholesale price index.

Aggregate Elasticity

An extension of Allen's elasticity formula (p. 252) is made to derive the short-run elasticity of aggregate beef supply with respect to current cattle prices from the elasticity of the components:

$$E = \sum_{ij}\sum k_i e_{ij}$$

where k_i is the proportion of component i to total slaughter and e_{ij} is the supply elasticity of component i with respect to price j. This formula presumes that all beef quality prices change proportionately. The sign of E cannot be theoretically deduced from the components since e_{ii} are expected to be positive and $e_{ij \neq i}$ are expected to be negative. However, it is empirically hypothesized that prior negative estimates of E were due to model misspecification and the true short-run elasticity of aggregate beef supply with respect to current price is positive.

Data and Estimators

Based on production characteristics and market structure of the U.S. beef industry, this study develops a disaggregation scheme for slaughter beef among class (steers, heifers, and cows) and quality (choice, good, and utility) components. Even though there are no national data series which classify all slaughter beef into class and quality components, considerable information is available. With a generally plausible set of assumptions, proxy data series are constructed to accommodate the needs of the model.

Class Disaggregation

The USDA publishes beef slaughter data categorized among steers, heifers, cows, bulls and stags. These data relate to federally inspected beef slaughter and are reported in animal numbers. Beef slaughtered in nonfederally inspected plants is not reported by components. However, it appears reasonable to assume that the same percent breakdown among class components applies for nonfederally as for federally inspected beef slaughter [Ospina and Shumway 1978]. The animal number estimates thus derived are multiplied by average dressed weights, reported annually by class [USDA, *Livestock and Meat Statistics*], to yield class slaughter estimates in total weight.

Quality Disaggregation

Between 1956 and 1975, the period under investigation, 43 to 65 percent of all beef carcasses were graded by USDA (*Livestock, Meat, Wool Market News*). USDA defines eight grades: prime, choice, good, standard, commercial, utility, canner, and cutter. This study defines three grade equivalents: *choice* (which includes choice and prime), *good*, and *utility* (which includes standard and lower). Two underlying assumptions are made in order to estimate grade equivalents for all beef based on actually graded beef: (a) Because producers want the higher prices associated with higher grades, it is likely that most of the prime and choice steer and heifer beef produced is graded by USDA. Thus, it is assumed that the USDA-reported prime and choice figures cover all the higher quality steer and heifer beef produced. (b) Virtually all cows slaughtered classify as USDA commercial-or-lower grades (Williams, Bowen, and Genovese). The USDA-reported standard grade, consequently, is composed mainly of steer and heifer carcasses. It is then assumed that non-graded standard beef is the same percent of nongraded beef as graded standard beef is of graded beef.

These two assumptions permit allocation of non-graded beef among the two defined lower grades. By further assuming the same sex distribution within the two higher grades, the data series thus developed are treated as crude approximations of class and quality slaughter beef quantities. These data are available on request from the authors.

Other Data

Data on beef and dairy breeding herd inventories are published by the USDA in *Livestock and Meat Statistics*. Feeder cattle inventory is composed of steers and heifers (beef and other) 500 pounds and over, as reported in *Livestock and Meat Statistics*. Before 1970 the cattle inventory series were classified by class and age. Beginning in 1970 the classification was changed to its current form, by class and weight. The series are published in both classifications for the period 1965 to 1970, from which a conversion factor was derived to transform all previous data to the current classification. The underlying assumption is that the relationship between inventories in the old and new classifications remained constant.

The remaining USDA data for beef and pork are published in *Livestock and Meat Statistics* and in *Agricultural Statistics*. Broiler data are reported in *Poultry and Egg Situation*. Income, population, and price indexes appear in *Business Statistics* and in *Survey of Current Business*.

Price indexes across sexes are calculated for each grade and used in the steer and heifer slaughter supply equations in place of the individual steer and heifer prices. The correlation coefficient between contemporaneous feeder cattle inventory and beef breeding herd inventory variables is .984. Since estimation of the separate effects of individual inventory variables is not an objective here, the breeding herd inventory variable is deleted from the heifer slaughter supply equations in order to reduce collinearity problems. The combined effects of the proportion of heifers in the feeder cattle inventory less withdrawals for normal replacement should thus be reflected in the estimated feeder cattle inventory parameter of each slaughter heifer supply equation.

To conserve degrees of freedom, expected steer-corn and hog-corn price ratios are used in place of separate variables in the feeder cattle and breeding sow inventory equations.

Estimation

The model is specified as block recursive with two blocks. One contains a single equation with only the supply of slaughter broilers as an endogenous variable. Due to autocorrelation in the error term, it is estimated by generalized least squares. The other block contains the remaining fifteen simultaneous stochastic equations and is estimated by three stage least squares. The estimated model consists of 16 equations and seven identities. Twenty-three variables are endogenous and 19 are predetermined.

Price Expectations

The relevant price, current or expected, which motivates a particular type of decision is clearly distinguished in the economic model. Slaughter supplies are judged to respond most directly to current prices while inventories (or the assets required for future slaughter supplies) respond to expected prices. Since an increase in one quantity implies a decrease in the other, both decisions are affected indirectly by both sets of prices.

While current prices are observable, expected prices are not. The only representation of expected price provided by the marketplace is futures price [Gardner]. Two problems, however, preclude the general use of futures prices in this study: (a) futures markets for cattle and hogs are of recent origin, and (b) futures prices are not provided far enough into the future for the breeding herd inventory demand equation. Consequently, the unobservable expected price must be *defined* by the economist.

A number of alternative proxies for expected prices have been used in previous beef supply studies. In one way or another all have used current or past prices, or a combination of both. Most commonly used has been lagged price. However, since livestock prices generally are quite cyclical, the arbitrary use of lagged price seems unnecessarily naive. Although the average producer may not formulate price expectations as accurately as some econometric forecasting models, he likely considers the cycle. Thus, the approach taken here is to define expected prices as those predicted by a polynomial distributed lag model [Almon] of annual own-prices prior to the year of decisionmaking. Although this autoregressive model may not predict actual price as well as an econometric forecasting model [Leuthold, et al.], it does account for cyclical effects.

Alternative polynomial degrees ranging from 1 to 4 and lag lengths from 4 to 5 years were considered. The final choice was based on R^2's and ratios of coefficients to standard errors. In the feeder cattle and breeding sow inventory equations, expected steer slaughter prices are used in place of expected average steer-heifer slaughter prices since they are highly correlated; a quadratic polynomial with lag of 4 years was chosen. For expected pork prices the polynomial is quadratic with a lag of 5 years. For expected corn prices a cubic polynomial with a 5-year lag was used. R^2's are .83, .77, and .78, respectively.

The polynomial lag functions for steer slaughter price and corn price in year t+2 yielded very low R^2's, and were dominated by annual prices in the year prior to decisionmaking. In addition, steer slaughter prices in year t+2 were more highly correlated with lagged feeder steer prices than with lagged steer slaughter prices. Consequently, lagged feeder steer and corn prices are used as proxies for expected steer-heifer slaughter and corn prices in year t+2 in the breeding herd inventory demand equation.

Empirical Results

Estimated relationships for beef supply, imports and inventory appear in Table 1. Ninety-one percent of the estimated parameters have hypothesized signs, and 85 percent of the coefficient to standard error ratios are greater than 1.0.[8]

Domestic Supply

Of current prices, the estimated parameters on alternative price in the good steer supply equation and own-price in the cow slaughter supply equation are contrary to expectations. All other coefficients are as expected.

Increases in feeder cattle inventory are associated with increases in supplies of choice steers and choice and good heifers, and decreases in good steer slaughter; only the last sign is inconsistent with expectations. An increase of one animal in feeder cattle inventory is associated with increases of 598, 312, and 57 pounds in choice steer, choice heifer, and good heifer supply, respectively, and a decrease of 39 pounds in good steer supply. Combined heifer slaughter supply response to feeder cattle inventory is lower

[8]For small samples, the test statistic does not have a t distribution in simultaneous equation methods; the t ratio is regarded only as a guide [Kmenta, p. 584].

TABLE 1. Estimated Stochastic Equations for Supply, Inventories and Imports, Beef

Dependent Variable	Constant	PBFC	PBFG	PBFU	PCN	IFC	DIBH	IBH	IDH
		Explanatory Variables							
SSC	−6026385.9	333083.2	−337298.7		−2585375.4	597.5			
		(163546.4)[a]	(173247.3)		(413973.9)	(42.4)			
SSG	3682322.4	22.4	12861.6		997502.4	−38.9			
		(67812.6)	(72804.9)		(166349.1)	(21.5)			
SHC	−4273494.8	151708.9	−137364.9		−1551328.1	311.6	−77.3		
		(66405.2)	(71159.9)		(159350.8)	(18.8)	(20.0)		
SHG	−497309.2	−31384.4	52893.4		22727.9	57.2	−103.4		
		(39084.9)	(41469.9)		(95019.2)	(9.9)	(16.3)		
SCW	−2224803.4			−18162.4			−357.8	129.5	169.3
				(5265.7)			(21.9)	(12.2)	(24.5)

Dependent Variable	Constant	PBFU	PSTCN*	PPKCN*	PST*	PCN*	PV1	IBH	IBH1	RX*	DQUO	DUP
IFC	−508.2		274.6	−211.8			−1.7		.772			
			(41.5)	(36.1)			(13.6)		(.043)			
DIBH	249.3				145.5	−2109.1		−.039		13.5		
					(11.0)	(134.9)		(.016)		(8.6)		
IMP	−305910.3	30103.0									.949	−19269.5
		(4196.3)									(.154)	(3985.0)

Endogenous variables: SSC - choice slaughter steer supply, 1000 lb. carcass weight; SSG - good slaughter steer supply; SHC - choice slaughter heifer supply; SHG - good slaughter heifer supply; SCW - cow slaughter supply; IFC - feeder cattle inventory, thous.; DIBH - beef breeding herd inventory demand, thous.; IMP - beef import supply, 1000 lb. carcass weight; PBFC - wholesale choice beef price, \$/cwt; PBFG - wholesale good beef price; PBFU - wholesale utility beef price.

Predetermined variables: PCN - corn price, \$/bu.; IBH - beef breeding herd inventory, thous.; IDH - dairy breeding herd inventory; PSTCN* - expected steer-corn price ratio in year $t|t-1$; PPKCN* - expected hog-corn price ratio in year $t|t-1$; PST* - expected steer price in year $t+2|t-1$, \$/cwt; PCN* - expected corn price in year $t+2|t-1$, \$/bu.; PV1 - lagged wholesale vealer price, \$/cwt; IBH1 - lagged beef breeding herd inventory, thous.; RX* expected range condition index in year $t|t-1$; DQUO - beef subject to import quota for years 1965-75, 0 otherwise, 1000 lb. carcass weight; DUP - beef import slope dummy, PBFU for years 1965-75, 0 otherwise, \$/cwt.

Unless noted otherwise, each variable is specified in the same units as the preceding one.

[a]Estimated standard error.

than steer supply response (a) because heifer carcasses typically weigh less than steer carcasses and (b) because a substantial portion of heifers are withdrawn from feeder cattle inventory for normal breeding herd replacement.

Increases in demand for breeding herd inventory changes are associated with decreases in slaughter supplies of cows and choice and good heifers, as hypothesized. The magnitudes of these coefficients suggest that about one-third of the variation in breeding herd inventory demand occurs by altering the replacement-heifer retention rate, and the remaining two-thirds by varying the cow culling rate. The absolute sum of these three coefficients is 539, which exceeds average carcass weight of slaughter cows, 491 pounds, but is less than that of slaughter heifers, 556 pounds.

The coefficients on the beef and dairy breeding herd inventories (IBH and IDH) are larger than average carcass weight multiplied by typical replacement rates. Assuming replacement rates of 14 percent and 25 percent for beef and dairy, respectively [Ospina and Shumway 1978, p. 148], the above multiples would be 69 and 123. The estimated coefficients are substantially greater than these figures, implying that either replacement rates are actually higher (i.e., about 26 percent and 34 percent) or cows slaughtered (not slaughtered) due to increases (decreases) in breeding herd inventory are heavier than average.

Inventories

As hypothesized, feeder cattle inventories respond positively to the expected steer-corn price ratio and negatively to the expected pork-corn price ratio and to vealer price. The coefficient of lagged breeding herd inventory, .77, is a reasonable approximation of percent calf crop.

Demand for changes in breeding herd inventory responds positively to expected feeder steer prices and range conditions, and negatively to expected corn prices, as hypothesized. The magnitude of the partial adjustment coefficient, c (i.e., the negative of the beef breeding herd inventory parameter), is smaller than would be expected. It indicates a very long mean lag in adjusting to desired inventory, $(1-c)/c = 25$ years. This figure is not consistent with previous findings about beef cycles [Freebairn and Rausser].

Import Supply

Supplies of beef imports respond positively to current cow prices. In 1964, the Meat Import Bill introduced a system of quotas on beef imports. Although quotas have been binding for only a few years [USDA, *Livestock and Meat Situation*, February 1975], their presence has contributed to shifting out the intercept (DQUO) and increasing the slope (DUP) of the estimated import supply equation. The responsiveness of imports to domestic beef price changes was reduced by nearly two-thirds.

Supply Elasticities

Estimated supply elasticities are presented in Table 2 along with estimates derived from previous studies. Elasticities for heifers are greater than for steers. This finding is consistent with Jarvis' argument that the slaughter elasticity of females is normally greater since there is an alternative market for heifers, that is, for breeding stock (pp. 501-2). The cross elasticities with respect to corn price indicate that as corn price increases, producers reduce the amount of grain fed. This decreases both the total amount of slaughter beef and its average quality since fewer animals attain the choice grade and more are slaughtered at the good grade. With the negative relationship between current cow price and slaughter supply, it is inferred that current cow price movements are strong indicators of future slaughter prices and that the consequent demand for inventory change dominates the response.

The derived aggregate supply elasticity is positive, thus consistent with our empirical

TABLE 2. Domestic Slaughter Beef Supply Elasticities with Respect to Current Year Prices, Computed at Mean Price Levels

	Elasticity with Respect to the Price of				
Beef Category	Choice Beef	Good Beef	Utility Beef	Corn	All Beef
This study:					
Steers, choice	2.63	−2.50		−.65	
Steers, good	.00	.12		.31	
Heifers, choice	3.16	−2.68		−1.03	
Heifers, good	−.85	1.34		.02	
Cows			−.18		
All Beef				−.25	.14
	Fed Beef	Non-Fed Beef		All Beef	
Other studies:					
Reutlinger[a]					
Steers				.16 to .18	
Heifers				−.69 to .63	
Cows				−1.23 to −.92	
All Beef				−.17 to −.03	
Langemeier and Thompson					
Fed Beef	.23				
Non-fed Beef		−.55			
All Beef				.16[b]	
Tryfos				−.01	
Freebairn and Rausser[c]					
Fed Beef	0[d]				
Non-fed Beef		.61			
All Beef				.14	
Folwell and Shapouri					
Steer-Heifer	.06				
Other Beef		0[d]			
All Beef				.04	
Shuib & Menkhaus[e]					
Fed Beef	.14				
Non-fed Beef		−.97			

[a]Supply elasticities are with respect to prices lagged one year.
[b]Includes import supply.
[c]At 1970 prices.
[d]Neither current nor one-year lagged beef prices are included in these supply equations.
[e]Supply of number of federally inspected steers.

hypothesis.[9] The elasticity of supply with respect to corn price is higher in absolute value than the own price elasticity. This result suggests that grain price manipulation may be a more effective policy tool than beef price manipulation for altering beef output in the short run.

Pork and Broiler Supply

Pork and broiler supply and breeding sow inventory equations are presented in Table 3. The signs of the pork and corn price coeffi-

[9]One third of the product price parameters are statistically weak. However, treating those parameters as zero without re-estimating the remaining parameters still yields a positive aggregate supply elasticity, 0.19.

cients in the pork supply equation are contrary to theoretical reasoning, but consistent with prior empirical findings [Freebairn and Rausser; Tryfos]. Breeding sow inventories respond positively to the expected pork-corn price ratio. The sign of the expected steer-corn price ratio coefficient is contrary to expectation; thus, it does not support the notion of competition among beef and pork production suggested by the estimated feeder cattle inventory equation.

All coefficients in the broiler supply equation have the expected signs. This equation represents the recursive block of the model.

Demand

Table 4 presents the estimated demand equations for all three qualities of beef, for pork, and for broilers. Negative response of per capita demand to own-price changes and positive response to income changes are observed in all demand equations except good beef demand. While it may be reasonable to infer that good beef is the inferior good rather than utility beef (see Freebairn and Rausser; Langemeier and Thompson; Shuib and Menkhaus for evidence of a negative income elasticity for non-fed beef), serious consideration of good beef as a "Giffen" good seems logically untenable [Ospina and Shumway 1980]. At this point, the empirical finding of a negative income coefficient for good beef demand is viewed as a hypothesis in need of further testing. The positive own-price coefficient is also not ignored in the subsequent aggregation since it has a small standard error; however, it is viewed more as an empirical anomaly due to data limitations than as a serious hypothesis. The coefficient on the wholesale price index in this equation also is contrary to expectations.

Estimated beef demand elasticities are presented in Table 5 along with estimates derived from previous studies. The cross price coefficients indicate complementarity among certain qualities of beef (e.g., choice and good, good and utility) and among a particular beef quality (choice, good) and other meats. Similar results have been reported in previous studies. Freebairn and Rausser (1975) argue that while this is possibly due to spurious relations, it also could be explained by consumer preference for a varied meat menu.

TABLE 3. Estimated Stochastic Equations, Supply and Inventory, Pork, and Broilers

Dependent Variable	Explanatory Variables							
	Constant	PPK	PCN	ISW	NP	PPKCN*	PSTCN*	ISW1
SPK	−54126758.8	−20469.8 (13385.7)[a]	1872212.7 (359544.5)	913.0 (107.4)	7400476.0 (1014558.0)			
ISW	5564.3					50.9 (27.1)	52.6 (31.7)	.271 (.099)
		PBR1	PCN1	NC	ρ[b]	R^2		
SBR[c]	4236900.0	10925.6 (16927.3)	−666993.0 (192732.0)	37941.6 (4695.2)	.67	.98		

Endogenous variables: SPK - slaughter pork supply, 1000 lb. carcass weight; ISW - breeding sow inventory, thous.; SBR - slaughter broiler supply, 1000 lb. carcass weight; PPK - wholesale pork price, $/cwt.

Predetermined variables: PCN - corn price, $/bu.; NP - pork productivity index, pigs/litters; PPKCN* - expected hog-corn price ration in year t|t−1; PSTCN* - expected steer-corn price ratio in year t|t−1; ISW1 - lagged breeding sow inventory, thous.; PBR1 - lagged wholesale broiler price, $/cwt; PCN1 - lagged corn price, $/bu.; NC - broiler industry labor productivity

[a]Estimated standard error

[b]Autocorrelation coefficient

[c]Estimated by generalized least squares

TABLE 4. Estimated Stochastic Equations for Per Capita Demand for Choice, Good and Utility Beef, Pork, and Broilers

Dependent Variable	Explanatory Variables									
	Constant	PBFC	PBFG	PBFU	PBF	PPK	PBR	POM	PINC	WPI
QBFC	60.1	−.629	−1.123	.798				−.403	.029	−.297
		(.471)	(.527)	(.136)				(.090)	(.001)	(.092)
QBFG	15.3	−.813	1.508	−.463				−.146	−.004	.209
		(.329)	(.344)	(.066)				(.051)	(.001)	(.051)
QBFU	25.9	.938	−1.071	−.406				.525	.004	−.169
		(.106)	(.112)	(.026)				(.018)	(.0003)	(.018)
QPK	63.7				.276	−.777	.529		.007	−.066
					(.054)	(.037)	(.074)		(.001)	(.029)
QBR	34.9				.171	.121	−.583		.008	−.173
					(.032)	(.021)	(.043)		(.0004)	(.017)

Endogenous variables: QBFC - choice beef consumption, lb./capita; QBFG - good beef consumption; QBFU - utility beef comsumption; QPK - pork consumption; QBR - broiler consumption; PBFC - wholesale choice beef price, $/cwt.; PBFG - wholesale good beef price; PBFU - wholesale utility beef price; PBF - wholesale beef price, weighted average of all grades; PPK - wholesale pork price; PBR - wholesale broiler price; POM - wholesale weighted average price of pork and broilers.

Predetermined variables: PINC - personal disposable income, $/capita; WPI - wholesale price index.

Unless noted otherwise, each variable is specified in the same units as the one preceding it.

[a]Estimated standard error.

TABLE 5. Beef Demand Elasticities Computed at Mean Prices, Wholesale Level

Beef Category	Elasticity with Respect to the Price of: Choice beef	Good beef	Utility beef	Other meats	All beef	Income
This Study:						
Choice	−.71	−1.19	.69	−.43		1.97
Good	−1.14	1.99	−.49	−.19		−.30
Utility	1.92	−2.05	−.63	1.00		.43
All beef				−.01	−.57	.83

Beef Category	Fed Beef	Non-Fed Beef	All Beef	Income
Other studies:				
Langemeier and Thompson[a]				
Fed Beef	−.98	.30		2.20
Non-Fed Beef	1.42	−1.24		−1.31
All Beef			−1.06	1.17
Freebairn and Rausser[a]				
Fed Beef	−.83			1.61
Non-Fed Beef		−.43		−.21
Folwell and Shapouri[b]				
All Beef			−.40	1.00
George and King[a]				
All Beef			−.64[c]	.29

[a]Retail level.
[b]At 1973 levels.
[c]At farm level, George and King's elasticity estimate is −.42.

Short-Run Impact of Corn Price Changes — Policy Implication

Because major policy instruments are frequently invoked to alter free market grain prices, the short run impacts of a change in corn price on beef prices, supply and composition will be examined briefly. To evaluate such impacts, the reduced form model was derived by the procedure outlined by Goldberger (pp. 365-388).[10] The reduced form coefficients (impact multipliers) describe the current period effect of a change in the exogenous variable (in this case corn price) on the endogenous variables (beef supplies and prices) after taking into account the interdependencies among current endogenous variables [Goldberger, p. 369].

The estimated short-run impacts of a $1.00 per bushel increase in corn price are reported in Table 6. Signs of the beef supply and price multiplier estimates are consistent with those of the structural model. The estimated magnitudes imply that a $1.00 per bushel increase in corn price decreases current slaughter supply by 1.7 billion pounds; choice beef supply decreases 2.9 billion pounds, and good beef supply increases 1.2 billion pounds. Choice beef price increases $8.80 per cwt; good beef price increases $6.30 per cwt.

Based on 1976 supply and price levels, the impact multipliers indicate that a $1.00 per

[10]Two operating assumptions were imposed to permit the derivation: (a) weights used to calculate beef and other meat price variables were treated as constants, and (b) the per capita operator was treated as constant for each period and was used to specify demand equations in total quantities. Thus, the nonlinear identities were transformed into linear form.

bushel increase in corn price (45 percent of 1976 price) would result in a substantial decrease (25 percent) in choice beef supplies and a marked increase (13 percent) in good beef supplies in the same year. Choice beef price increases 15 percent and good beef price increases 11 percent. The choice-good quantity ratio decreases from 1.32 to .88 (see Table 6), while the choice-good price ratio increases from 1.05 to 1.08. Estimated changes in the composition of slaughter beef supply are also presented in Table 6. Major decreases are in choice steer and heifer supply. The most important increase is in good steer supply.

Conclusions

This study has focused on conceptual problems and empirical estimation in modeling slaughter beef supply. Three basic issues were addressed in model specification: disaggregation according to animal class and quality components, differentiation between current and expected price effects on slaughter supplies, and simultaneity in slaughter supply, demand, and inventory accumulation decisions. An econometric model was developed to estimate supply, inventory, and demand relations for slaughter beef in the U.S. for the period 1956 to 1975.

Although some are statistically weak, most estimated beef supply and inventory parameters have the expected signs. Positive own-price and negative alternative price coefficients are estimated for choice steer and heifer supply. Supply of choice beef is negatively related and supply of good beef positively related to corn price. Price parameters contrary to expectations are estimated on own-price in the cow slaughter supply equation and alternative price in the good steer equation. Aggregate short-run beef supply elasticity derived at mean prices from the component estimates is positive and consistent with our empirical hypothesis. It is near

TABLE 6. Estimated Effects of a $1.00 per Bushel Increase in the Price of Corn on Beef Supply, Composition, and Price

		Variable Levels,	
Variable	Multiplier, Mean Estimate	Actual Levels, 1976	Predicted Levels Following Corn Price Increase
	(million lbs)	(percent of total beef supply)	
SSC	−1,800	29	24
SSG	1,079	22	28
SHC	−1,091	16	12
SHG	82	12	13
SCW	79	20	22
SBF	−1,650	100	100
	($/cwt)	(ratio)	
PBFC	8.8		
PBFG	6.3		
PBFU	−4.4		
PBF	5.3		
SBFC/SBFG		1.32	.88
PBFC/PBFG		1.05	1.08

Variables: SSC - choice slaughter steer supply, SSG - good slaughter steer supply, SHC - choice slaughter heifer supply, SHG - good slaughter heifer supply, SCW - slaughter cow supply, SBF - total slaughter beef supply, PBFC - wholesale choice beef price, PBFG - wholesale good beef price, PBFU - wholesale utility beef price, PBF - wholesale beef price (weighted average of all grades), SBFC - choice slaughter beef supply, SBFG - good slaughter beef supply.

the upper limit of prior estimates. Composition of slaughter beef supply is highly dependent on beef and grain prices. The corn price elasticity of supply for all beef is higher in absolute value than the own-price elasticity. Both the corn price elasticities derived from the structural model and the estimated reduced form impact of a change in corn price document the sensitivity of beef supply, composition, and prices to free market and/or policy-induced changes in corn price.

On the demand side, all own-price income coefficients show the expected signs except in the good beef demand equation. Most cross price coefficients do not support the notion of substitutability among beef types and between beef and other meats.

In drawing these empirical conclusions, several limitations, which are important candidates for further evaluation, must be noted:

(a) Although pragmatically defensible, the disaggregation procedures are based on rules that are at least partially arbitrary. Equal justification could perhaps be found for alternative rules. Existing data pose a serious limit on the confidence that can be placed in any beef supply response estimate.

(b) The process by which producers formulate price expectations is not clearly understood. Because no historical data series exists for expected beef prices, such variables must be constructed by the economist and consequently are subject to non-unique definitions. The specification for expected prices likely could be substantially improved over that used here. Certainly, the justification is weak for excluding current price from the expected price specification for the breeding herd inventory demand equation.

(c) Since some of the questions posed here are dynamic in nature, further validation of the dynamic attributes of the model is an important priority for future work.

(d) The model is derived and estimated assuming perfect competition. The effects of risk on beef supply response were not evaluated.

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