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A Quarterly Econometric Simulation Model of
the U.S. Livestock and Meat Sector

by

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## Introduction

Policy analysts are often confronted with determining the economic impacts of a proposed policy change. The assessment of the policy analyst is often used by decision makers to determine whether the policy should be instituted or to formulate ways to respond if the policy is instituted. Similarly, it is worthwhile to assess the economic consequences of a proposed technology change. The results of such an analysis allows those affected to make plans before the technology arrives to adapt to the changes in the economic environment which will likely occur. One tool to analyze these policy and technology changes on an ex ante basis is an econometric simulation model. These policy simulation models have gained acceptance as a way of guiding policy analysts' evaluations of a policy or technology; however, policy analysis still remains largely an art of accounting for factors which are beyond estimation as indicated by the following quote from Pindyck and Rubinfeld p. 405:

> "*Usually forecasters and policy makers allow for a considerable amount of interaction between their models and their judgement. In this way a model becomes more than just a mathematical forecasting tool and also serves as a means of processing and making consistent information available that was not originally contained in the model.* "

This paper develops a quarterly dynamic simulation model of the U.S. livestock sector which is useful for both policy analysis and technology assessment. The model includes a complete representation of the livestock and meat supply sector, processing or margin sector and meat demand. First the conceptual framework for the model will be outlined. Second, the data used for the model will be presented and, finally, the estimation and validation statistics of the model will be presented.

## Conceptual Framework

### Livestock and Meat Supply

While there are relatively few full-scale livestock sector models developed and used for economic simulation (Weimar and Stillman 1990; Peel 1989; Arzac and Wilkinson 1979), there is vast literature reporting industry models and issues in modeling the various components of the livestock sector. These studies cover a set of issues related to development of livestock commodity models, behavioral relationships, estimation procedures, dynamics and data.

Attempts to model the supply behavior of the livestock industry have been a mixture of economic theory and ad hoc techniques, although supply dynamics have received considerable attention in agricultural economics. In general, producers' decisions on production levels are affected by the expected prices they will receive at the time of sale of the commodity. That is, if the producer expects output prices to be favorable, it is likely that breeding herd expansion will occur so that more production will be available at the time of higher prices. However, future prices are uncertain, so the producer must formulate decisions based on price expectations.

The general framework to be used for this model is the partial adjustment-adaptive expectations framework initially proposed by Nerlove (1956). In this model, current values of the independent variables determine the "desired" value of the dependent variable. The starting point of the framework is exemplified by Equation 1.

$$y_t^* = ax_t + u_t \quad (1)$$

In Equation 1, $y_t^*$ is the optimal level of output in time t, and $x_t$ represents a vector of exogenous and predetermined variables. However, only a portion of the adjustment towards the optimal level of output occurs within a time period. Equation 2 represents the adjustment structure, and by substituting Equation 1 into Equation 2, the general formulation of the model shown by Equation 3 is reached.

$$y_t - y_{t-1} = \gamma(y_t^* - y_{t-1}) \tag{2}$$

$$y_t = a\gamma x_t + (1-\gamma)y_{t-1} + \gamma u_t \tag{3}$$

This model leads to exactly the same reduced form equation as the adaptive expectations model, except that it does not induce additional serial correlation in the disturbances if there was none to start with. This model formulation has been quite popular for representing supply response for those processes which have a cyclical component, and production does not react immediately to the price levels observed.

The partial adjustment-adaptive expectations framework allows the incorporation of systematic price expectations to enter the model. However, the biological lags inherent in the production of livestock offer prior information on the production process which should be used to advantage.

Explicit incorporation of biological structure into a livestock supply sector was first done by Chavas and Johnson (1982) in estimating broiler supply response. In their framework, the production process in livestock is viewed as a succession of stages where capital from previous stages is transformed to the next stage by inclusion of variable inputs at the stage of production. Thus, if time is required for each transformation, the production occurs over a continuum restricted by the biological production lags. Similar to the framework of Chavas and Johnson, biological relationships will be used as prior information to determine appropriate lags for the partial adjustment framework.

The conceptual form of the dynamic supply response model incorporates the partial adjustment hypothesis and biological restrictions. However, Coleman (1983) suggests that insufficient attention has been given to the form in which price variables enter the supply equations. Many researchers (Chavas and Johnson 1982; Grundmeier et al. 1989; Skold et al. 1989; Jensen et al. 1989; Freebairn and Rausser 1975; Stillman 1985; and Wahl 1989) have incorporated the output price and the most relevant input price in their analysis either independently or as a ratio of output price to input price. To allow for response to alternative feed prices, a feed cost index will be used in a price ratio format similar to previous studies. This allows for improved response to feed cost changes.

Farm-Retail Margin

There are essentially three specifications frequently used for margin specification mark-up (Heien 1977, 1980; Waugh 1964; and George and King 1971), relative pricing (Gardner 1975; Wohlgenant and Mullen 1987), and the marketing cost model where the margin is considered to be a bundle of marketing services. Although each is defensible under certain assumptions, it has been shown that the appropriate specification depends on the purpose of the margin (Wohlgenant and Mullen), the length of period involved (Heien 1980; Lyon and Thompson 1991); the spatial aggregation (Lyon and Thompson), and the level of concentration in the processing industry (i.e., the issue of asymmetric pricing examined by Heien (1980) and Kinnucan and Forker 1987). In addition, the appropriate specification depends on assumptions about the processing technology and the direction of price causality (i.e., whether farm price causes retail price or retail price causes farm price). This relates to the issue of the degree of supply fixity in the short run.

Although each of these factors is important, the most important consideration is the structure of the supply and demand sectors of the current model. The primary objective in the present context is to provide a price transmission equation which forecasts accurately and allows for analysis of the impacts on supply and demand from policy or technology changes. Wohlgenant and Mullen (1987) have suggested that in cases where the model is intended for policy applications relating to shifts in both retail demand and farm supply, then preference should be for the relative price model since it can account for shifts in both supply and demand. The supply side is estimated such that the supply is not completely predetermined in the quarterly framework. Thus, the primary price determination must occur at the retail level so that the direction of causality goes from retail price to farm price, where retail price is a function of all quantities supplied. Thus, the margin to be specified will be a relative price scheme as depicted by Equation 4.

(4) $$M_t = b_1 P_{rt} + b_2 P_{rt} Q_t + b_3 IC_t + \epsilon_t \Rightarrow \text{relative price model}$$

where $M_t$ is the farm-retail price spread, $P_{rt}$ is the retail price of the commodity, $Q_t$ is the per capita quantity of the commodity produced, and IC is an index or indicator of marketing costs.

Meat Demand

There are two aspects of the demand system theoretical component--the use of a price dependent or inverse demand system, and the selection of the AIDS demand system. The discussion will proceed with the justification and validation of the use of an inverse demand system, followed by the specification and justification of the AIDS system in its price dependent form for use in estimation.

Prior to presenting the theoretical derivation of the *inverse* demand system, it is necessary to establish that the *inverse* and not the *regular* demand system is indeed necessary. That is, the argument must be established that prices are a function of quantities and expenditures and that quantities are not a function of all prices and expenditures specified in the regular demand system. Theoretically, it makes no difference whether prices are expressed as a function of quantities or whether quantities are expressed as a function of prices (see, e.g., Katzner 1970; Salvas-Bronsard et al. 1977; Laitinen and Theil 1979; and Anderson 1980).

From an empirical standpoint, inverse and regular demand functions are not equivalent. For statistical purposes, the right-hand side variables should be those variables over which the decision maker has no control. In most cases, the consumer is a price taker and a quantity adjuster, thus the regular demand system is indicated. However, in the case of quarterly meat demand, it can be argued--at least for fresh meat products--that prices are set so that consumers are induced to buy all available quantities. Thus, price would be a function of quantity and the inverse demand system would be appropriate. Historically, price dependent meat demand systems have been widely used since Fox (1953) recognized that prices may be set to induce consumers to buy all available supply quantities because supply cannot be adjusted in the short-run due to the length of the gestation and production cycles for beef and pork. The appeal for a demand system in price dependent form may also be made from the standpoint of simultaneity in prices and quantities. The simultaneous equation bias for a price-dependent demand function approaches zero as the supply price elasticity approaches zero, ceteris paribus (Dahlgran 1987). However, Thurman (1986) contradicts this notion of supply fixity for broilers in an annual framework and suggests testing with the Wu-Hausman test for simultaneity in a supply-demand framework. However, the endogeneity problem is largely avoided through the use of simultaneous equation estimation techniques such as three-stage least squares (3SLS) or iterative three stage least squares (IT3SLS). Following is the derivation of consumer demand in the price dependent framework, followed by its application to the almost ideal demand system.

Deaton (1979) and Deaton and Muellbauer (1980b) make use of the relationship between the distance function and the ordinary cost function to derive the inverse demand specification using commonly applied duality concepts. The dual relationship between the distance function and the cost function has been used extensively in production literature. Its most extensive exposition in production is given by Fuss and McFadden (1978) and Shepard (1970). Only very recently has this procedure been used as an application to AIDS reparameterization (Eales and Unnevehr 1991; Visa and Moschini 1991; and Buhr and Kesavan 1992). Because the AIDS model is explicitly derived from the PIGLOG (Price Independent General Log) cost function, it seems only natural that the inverse AIDS should be derived from the dual distance function. A synopsis of the theoretical underpinnings of the duality between the distance function and the cost function and, hence, the duality between inverse demand functions and regular demand functions can be found in Buhr (1992).

The analogy of the distance function and the cost function suggests that the well known derivation of the regular AIDS by Deaton and Muellbauer (1980a) using the PIGLOG cost function as a starting point may be paralleled with the starting point as the distance function rather than the cost function. This inverse approximation will be referred to as the AAIIDS (Approximate Almost Ideal Inverse Demand System) model in subsequent derivations.

The primary objective of Deaton and Muellbauer in developing the AIDS model was to derive a system of the form $w_i = \alpha_i + \beta_i \ln(x)$; where, $w_i$ is the expenditure share of the $i^{th}$ commodity, x is total expenditure, and $\alpha_i$ and $\beta_i$ are parameters to be estimated. This form of a demand equation provides for nonlinear Engel curves with a linear specification. In the AIDS, the objective is to add prices while maintaining this form of the demand specification. Similarly, for the AAIIDS, the objective is to add quantities to this specification and maintain the structure.

For the regular AIDS model, Deaton and Muellbauer start with an arbitrary set of preferences known as the PIGLOG (price independent general log) class, and these preferences are represented via the PIGLOG cost function which defines the minimum expenditure necessary to attain a specific utility level at given prices. This specification is particularly desirable because PIGLOG preferences have the property of consistent aggregation from the household to the market level. The PIGLOG cost function is given as:

(5) $$\ln C(u,p) = a(p) + u \cdot b(p).$$

From the duality of distance functions and cost functions, it is apparent that for prices and quantities which are conjugate (i.e., prices and quantities which satisfy the minimization criteria), q can simply be substituted for p in the PIGLOG cost function to arrive at the PIGLOG distance function represented as:

(6) $$\ln D(u,q) = a(q) + u \bullet b(q).$$

Now, from the derivative property of the distance function $\partial d(u,q)/\partial q_i = a_i(u,q) = r_i = p_i/x$ which is the inverse compensated demand function. Again, assuming that p and q are conjugate,

(7) $$\frac{\partial \ln d(u,q)}{\partial \ln q_i} = w_i(u,q) = w_i(u,p) = \frac{\partial \ln c(u,p)}{\partial \ln p_i}$$

where $w_i$ is the expenditure share of the $i^{th}$ commodity. Applying the derivative property to the PIGLOG distance function one arrives at the share equation as shown in Equation 8.

(8) $$\frac{\partial \ln D}{\partial \ln q_i} = \frac{\partial a(q)}{\partial \ln q_i} + u \cdot \frac{\partial b(q)}{\partial \ln q_i} = w_i(u,q)$$

It is also known that just as the inversion of the cost function leads to the indirect utility function, inversion of the distance function leads to the inverse direct utility function if d(u,q)=1 (i.e., the consumer is on the highest obtainable indifference curve, given the implied budget constraint) which is asserted for this argument. Thus, inverting the distance function gives:

(9) $$u = \frac{\ln D - a(q)}{b(q)} = v(q)$$

which is the inverse direct utility function. By substituting this expression of u into the share Equation 8, the expression for the share equation becomes,

$$w_i = \frac{\partial a(q)}{\partial q_i} - \frac{a(q)}{b(q)} \cdot \frac{\partial b(q)}{\partial \ln q_i} + \frac{\partial b(q)}{\partial \ln q_i} \ln D \tag{10}$$

Now, if

$$\alpha_i = \frac{\partial a(q)}{\partial q_i} - \frac{a(q)}{b(q)} \frac{\partial b(q)}{\partial \ln q_i} \tag{11}$$

and,

$$\beta_i = \frac{\partial b(q)}{\partial \ln q_i} \tag{12}$$

then the PIGLOG distance function yields the form of the share equation

$$w_i = \alpha_i + \beta_i \ln D(u,q) \tag{13}$$

which is similar to that of the regular AIDS derivation. However, it is worth noting that the aggregation properties of this term may not be equivalent to those of the regular AIDS system. The distance function is not self-dual as the cost function is with expenditure (i.e., $c(u,p)=p_n q_i=x$ at optimal levels). Thus, an investigation of the aggregation properties is warranted but is beyond the scope of this study.

Having shown that the PIGLOG distance function does indeed result in the form of the share equation desired, this must be extended to include quantities so that the AAIIDS model can be properly parameterized. Following Deaton and Muellbauer's procedure with the regular AIDS model, specific functional forms are chosen for a(q) and b(q) so that the resulting PIGLOG distance function is a flexible functional form. Specifically, a(q) is chosen to be the translog function and b(q) is chosen to be the Cobb-Douglas functional form. That is,

(14) $$a(q) = \alpha_0 + \sum_i \alpha_i \ln q_i + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln q_i \ln q_j$$

and,

(15) $$b(q) = \beta_0 \prod_k q_k^{\beta_k}.$$

Thus, the AAIIDS distance function can be written as

(16) $$\ln d(u,q) = lnD = \alpha_0 + \sum_i \alpha_i \ln q_i + \frac{1}{2}\sum_i \sum_j \gamma^*_{ij} \ln q_i \ln q_j + u\beta_0 \prod_k q_k^{\beta_k}$$

As before, the compensated inverse share can be derived by differentiating the distance function with respect to $q_i$ and inverting the distance function to derive the direct utility function, then substituting the share equation to yield the uncompensated share equation. These steps are illustrated by the following four equations:

(17) $$\frac{\partial lnD}{\partial \ln q_i} = w_i(u,q) = \alpha_i + \sum_j \gamma_{ij} \ln q_j + \beta_i u \beta_0 \prod_k q_k^{\beta_k}$$

(18) $$where, \quad \gamma_{ij} = \frac{1}{2}(\gamma^*_{ij} + \gamma^*_{ji})$$

(19) $$u\beta_0 \prod_k q_k^{\beta_k} = lnD - \alpha_0 - \sum_i \alpha_i \ln q_i - \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln q_i \ln q_j$$

(20)

$$w_i(u,q) = \alpha_i + \sum_j \gamma_{ij} \ln q_j + \beta_i [lnD - \alpha_0 - \sum_i \gamma_i \ln q_i - \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln q_i \ln q_j]$$

Equation 17 is the compensated share, Equation 19 is the direct inverse utility function, and 20 is the uncompensated share equation. At optimal levels, it is known that D(u,q) = 1 just as C(u,p) = x for the regular demand system, so that the last equation above is simplified to:

(21) $$w_i = \alpha_i + \sum_j \gamma_{ij} lnq_j + \beta_i [-\alpha_0 - \sum_i \gamma_i lnq_i - \frac{1}{2}\sum_i \sum_j \gamma_{ij} lnq_i lnq_j]$$

where, the term in brackets is defined as **lnQ** and is analogous to **lnP** in the AIDS system. Thus, the final form of the approximate inverse almost ideal demand system (AAIIDS) may be written as:

(22) $$w_i(u,q) = \alpha_i + \sum_j \gamma_{ij} \ln q_j - \beta_i lnQ.$$

This is the specification to be estimated for the inverse meat demand model.

From this specification, it is possible to derive the inverse elasticities or flexibilities, for the AAIIDS model. As with the regular AIDS model and using Anderson's (1980) derivations, the general formula for calculating flexibilities are shown by Equations 23-25. The own and cross price flexibilities of the AAIIDS model is defined as:

(23) $$\phi_{ij} = -\delta_{ij} + \frac{\gamma_{ij} - \beta_i (w_j + \beta_j lnQ)}{w_i}$$

Although this represents the uncompensated flexibility for the AAIIDS, the compensated flexibility for the AAIIDS model may be calculated exactly was done for the AIDS mode Although each of these factors is important, the most important consideration is the structure of the supply and demand sectors of the current model.1. The compensated flexibilities for the AAIIDS model are:

(24) $$\Omega_{ij} = \phi_{ij} - w_j \phi_i$$

where $\phi_i$ is the scale elasticity of the AAIIDS, which by applying the definition of the scale elasticity to the AAIIDS model yields:

(25) $$\phi_i = -1 - \frac{\beta_i}{w_i}.$$

Using the flexibilities, the parameter restrictions on the AAIIDS model can be derived as:

(26) $$\sum_i \alpha_i = 1 \quad \sum_i \gamma_{ij} = 0 \textit{ and } \sum_i \beta_i = 0 \quad \rightarrow \quad \textit{adding up}$$

(27) $$\sum_j \gamma_{ij} = 0 \quad \rightarrow \textit{ homogeneity}$$

and

(28) $$\gamma_{ij} = \gamma_{ji} \quad \rightarrow \textit{ symmetry.}$$

*The* results provide the conceptual framework necessary to pursue the empirical estimation of the AAIIDS model.

## U.S. Quarterly Livestock Data

Accounting for stock-flow relationships in livestock production is necessary for specifying the quarterly pork production system. However, accurately accounting for the stock-flow relationships is difficult with the use of secondary data sources since the frequency of data reporting may vary, the definition of a variable may change, or the necessary data may not be reported at all. Production data is obtained from various USDA sources (see references). The series of pork production variables used and the frequency of their reporting, are:

1. Pork data reported monthly by the USDA:
   a. U.S. commercial hog slaughter.
   b. Federally inspected hog slaughter, by class (barrows and gilts, sows, stags and boars).
   c. Percentage of federally inspected hog slaughter, by class.
   d. Live hog imports and exports.

2. Pork data reported quarterly by the USDA:
   a. Breeding herd inventory for 10 states.
   b. Barrow and gilt inventory for 10 states.
   c. Pig crop.
   d. Sows farrowing.

3. Pork data reported semi-annually by the USDA
   a. U.S. breeding herd inventory.
   b. U.S. barrow and gilt inventory.

Although many other variables such as prices enter the production system, these variables represent the primary production variables which represent the stocks and flows of hogs through the production system. These variables are necessary to define the biological identities of the pork supply sector. The two primary identities are:

1. Breeding herd $\text{inventory}_t$ = breeding herd $\text{inventory}_{t-1}$ + breeding herd $\text{additions}_{t-1}$ - breeding herd $\text{slaughter}_{t-1}$.

2. Barrow and gilt $\text{inventory}_t$ = barrow and gilt $\text{inventory}_{t-1}$ + pig $\text{crop}_{t-1}$ - breeding herd $\text{additions}_{t-1}$ - barrow and gilt $\text{slaughter}_{t-1}$ + live hog $\text{imports}_{t-1}$ - live hog $\text{exports}_{t-1}$ - death $\text{loss}_{t-1}$.

Death loss represents a residual category which includes actual death loss, but also contains any errors which occur due to misreporting.

The considerations regarding stocks and flows apply to beef as well as pork. However, because of the longer biological relationships in beef production, virtually no quarterly production data (other than slaughter) is available for beef. The series of beef production variables used and their reported period include the following:

1. Beef data series reported at least quarterly by the USDA.
   a. Imports and exports of live cattle.
   b. Commercial cattle slaughter, by age, and gender.

2. Beef data series reported semi-annually by the USDA.
   a. Total cattle inventory, by age and gender.

3. Beef data series reported annually by the USDA.
   a. Calf crop
   b. Death loss.
   c. Farm slaughter.
   d. Annual cattle balance sheet.

The primary objective is to obtain consistent quarterly estimates of these variables, which will allow for the calculation of the quarterly stock-flow relationships of beef production. Breeding herd inventory and steer and heifer inventory are the two primary biological identities, with each period's inventory calculated from flows through the system. These two identities are:

1. Breeding herd inventory$_t$ = breeding herd inventory$_{t-1}$ + breeding herd additions$_{t-1}$ - cow slaughter$_{t-1}$ - breeding herd death loss$_t$.

2. Steer and heifer inventory$_t$ = steer and heifer inventory$_{t-1}$ + calf crop$_{t-1}$ - steer and heifer slaughter$_{t-1}$ - calf slaughter$_{t-1}$ + live imports$_{t-1}$ - Live exports$_{t-1}$ - Death loss$_{t-1}$.

Notice that these two identities combined would provide an inventory of all cattle. Of the data necessary to calculate these quarterly identities, only slaughter data and import-

**export** data are available on a quarterly basis. All others are available only semi-annually or annually.

Broiler production data is also rather limited. However, in contrast to the beef and pork data, broiler data is available on a monthly basis which makes aggregation to quarters a simple summing or averaging procedure. The primary problem is that virtually no inventory data exists. The only data available for flow variables are layers placed in hatchery supply flocks, chicks hatched, federally inspected slaughter, and commercial slaughter. Thus, it is not possible to provide well defined biological identities, as with beef and pork. Since the biological constraints of broiler production fit well within one quarter, it is not necessary to impose quarterly identities on the system. Therefore, the broiler production sector will be estimated largely as a flow relationship and with no identities. The broiler production data is aggregated to a fiscal quarter basis as was done with the hog data, so that these two sectors are on an equivalent time period basis. It would have been desirable to obtain beef data on the same time period basis, but with data limitations this was not possible.

Because of the above data limitations, it is necessary to estimate some of the quarterly variables not directly available. One of the first issues is to reconcile pork production data. Inventory data is not reported on a calendar quarter basis. Therefore, it was necessary to adjust slaughter to a similar basis to use the appropriate biological identities. A complete discussion of this procedure is in Buhr (1992).

A more difficult situation arises in beef. Many necessary values are only reported on an annual or semi-annual basis. This required that quarterly estimates be derived. A procedure used by Goodwin and Pippin (1990) was adopted for this study. A complete discussion of the reconciliation procedure is provided by Buhr (1992). Also, all data is available from the author on request.

## U.S. Livestock Model Specification and Estimation

The specification of the model follows the conceptual framework and utilizes the data provided. Table 1 provides the variable definitions to be used for the livestock model estimation. The estimated U.S. livestock sector model is provided in Table 2. Because of the simultaneous and non-linear nature of the specification, non-linear 3SLS estimation was used for the system, and the SAS ETS package was used for estimation. Quarterly production, consumption, and price data for the period 1973-1989 was used for the estimation. The coefficient parameters are provided in each equation, coefficient t-statistics are given in parenthesis under the corresponding estimate, and $R^2$ values and Durbin-Watson (DW) or Durbin-H (DH) statistics are provided at the end of each estimated equation. Where necessary, equations were corrected for serial correlation and the correction equation is provided at the end of a corrected equation. Instrumental variables for the estimation included exogenous variables and their first and second order approximations.

### Beef supply sector

There are two feed cost variables which enter the beef supply sector. The first is the feed cost associated with fed cattle production (Equation 2, Table 2). This is specified as a weighted average of corn and corn silage, which are two primary feed inputs to fed cattle production. The second is the feed cost associated with the beef cow herd (Equation 3). This is comprised of hay and corn, which are the two primary feed inputs to the beef cow herd. These feed cost variables will be one of the primary economic variables which enter the beef supply system.

Future beef production is primarily determined by current decisions to cull from or add to the breeding herd. Cow slaughter (Equation 4, Table 2) and heifer additions (Equation 5) represent the producer's decision to reduce or expand the breeding herd. Cow slaughter is specified using a logistic function. The logistic functional form allows direct imposition of the restriction that cow slaughter cannot exceed the cow inventory. **A** term for the change in the dairy cow herd is included to provide a reduced form representation of any changes in dairy cow inventory which may affect cow slaughter. Quarterly dummy variables are included to account for seasonality. The variable D769 represents a dummy variable applied to the years 1976-1979; during this period a very sharp decrease in cow slaughter occurred. Equation 5 represents the addition of heifers to the breeding herd. Heifer additions are defined as heifers which have calved, thus the lags are representative of typical pre-conditioning and gestation periods. Once it is determined that heifers will be added it is necessary to feed them to appropriate breeding weight, which will be followed by approximately a nine month gestation penod. Heifer additions are highly seasonal because additions are reported as heifers that have calved their first calf, and it is common for calving to occur in the spring due to weather conditions. Heifer additions are independently estimated for each quarter to allow for differing responses within the quarters. Heifer additions were also corrected for first and fourth order autocorrelation. Once the producer's addition and culling decisions are made, the cow inventory is determined by identity (Equation 6).

Table 1. Definitions of model variables

Jointly Determined Variables

| | | | |
|---|---|---|---|
| $S_i$ | Expenditure share | $M_i$ | Retail - farm margin ($/lb.) |
| $FP_i$ | Farm price ($/cwt.) | HA | Heifer additions (1000 hd.) |
| $I_i$ | Inventory (1000 hd.) | CC | Calf crop (1000 hd.) |
| GA | Gilt additions (1000 hd.) | PC | Pig crop (1000 hd.) |
| $CS_i$ | Commercial slaughter (1000 hd.) | KL | Chicks in hatchery flock (1000 hd.) |
| $PC_i$ | Per capita retail consumption (lbs.) | $TD_i$ | Total dom. disappearance (mill. lbs.) |
| $PCC_i$ | Per capita carcass consumption (lbs.) | FL | Cattle placed on feed (1000 hd.) |
| $SP_i$ | Commercial production (mill. lbs.) | $TS_i$ | Total supply (mill. lbs.) |
| $LS_i$ | Live-weight production (mill. lbs.) | KH | Broiler chicks hatched (1000 hd.) |
| $CW_i$ | Carcass weight (lbs.) | $LW_i$ | Live weight (lbs.) |
| $FS_i$ | Federally inspected slaughter (1000 hd.) | $GC_i$ | Grain consuming animal unit |
| $HP_i$ | High protein animal unit | $NM_i$ | Margin: $(R_i - FP_i)/CPI$ |

Exogenous and Predetermined Variables

| | | | |
|---|---|---|---|
| CPI | CPI , all goods (1984=100) | $FC_i$ | Feed cost index (dollars) |
| PG | Corn price ($/bu.) | PS | Corn silage price ($/ton) |
| PH | Average all hay price ($/ton) | PM | Soymeal price, 44% Decatur ($/ton) |
| $BS_i$ | Beginning stocks (mill. lbs.) | $ES_i$ | Ending stocks (mill. lbs.) |
| $DL_i$ | Death loss (1000 hd.) | $SF_i$ | On-farm production (mill. lbs.) |
| $CS_L$ | Commercial calf slaughter (1000 hd.) | $FS_i$ | On-farm slaughter (1000 hd.) |
| $LI_i$ | Live imports (1000 hd.) | $LX_i$ | Live exports (1000 hd.) |
| $I_i$ | Imports (mill. lbs.) | $X_i$ | Exports (mill. lbs.) |
| $PC_T$ | Per capita retail turkey consumption (lbs.) | $CV_i$ | Carcass-retail weight conversion factor |
| IN | Real interest on feeder cattle loans (%) | $LV_i$ | Live-carcass weight conversion factor |
| $CS_{BS}$ | CS bulls, boars, and stags (1000 hd.) | $BY_i$ | Byproduct value ($/lb.) |
| CBR | Average rainfall in corn-belt (inches) | POP | U.S. population |
| $MK_i$ | Avg. marketing cost, red meat ($/lb.) | XM | Total meat expenditures |
| D769 | 1 if year =1976-79; 0 otherwise | D1 | 1 if quarter = 1; 0 otherwise |
| D2 | 1 if quarter = 2; 0 otherwise | D3 | 1 if quarter = 1; 0 otherwise |
| D4 | 1 if quarter = 4; 0 otherwise | | |

i = B for beef, P for pork, K for chicken, T for turkey, F for fed beef, N for non-fed beef, Y for young chicken, O for other chicken, C for beef cows, D for dairy cows, S for steers, H for heifers, BG for barrows and gilts, W for sows, L for calves, DC for diary + beef cows.

Table 2. U.S. livestock sector model

### Beef Supply Sector

(1) $PS = PG*10$

(2) $FC_F = (1731.82/56)*PG + (2361.57/2000)*PS$

(3) $FC_C = (1682.65/2000)*PH + (352.22/56)*PG$

(4) $CS_{DC} = I_{DC}/(1+\exp(\underset{(45.24)}{4.17} + \underset{(6.78)}{0.0085}*((FP_S+FP_{S,t-1}+FP_{S,t-2}+FP_{S,t-3})/4)$

$- \underset{(-4.40)}{0.0046}*((FC_c+FC_{c,t-1}+FC_{c,t-2}+FC_{c,t-3})/4)$

$+ \underset{(0.97)}{0.0023}*((IN+IN_{t-1}+IN_{t-2}+IN_{t-3})/4) + \underset{(0.23)}{0.00002}*(I_D - I_{D,t-1})$

$- \underset{(-1.28)}{0.044}*D2 - \underset{(-5.27)}{0.184}*D3 - \underset{(-7.23)}{0.279}*D4 - \underset{(-6.29)}{0.0195}*T + \underset{(3.65)}{0.064}*D769 - \underset{(-18.73)}{0.0004}*CS_{DC,t-1}))$

$R^2 = 0.92 \qquad DH = 0.82$

(5) $HA = (\underset{(2.88)}{38.10}*((FP_{S,t-2}+FP_{S,t-3}+FP_{S,t-4}+FP_{S,t-5})/4)$

$- \underset{(-1.22)}{3.83}*((FC_{F,t-2}+FC_{F,t-3}+FC_{F,t-4}+FC_{F,t-5})/4) + \underset{(5.21)}{0.057}*(CC_{t-6}+CC_{t-7}+CC_{t-8}+CC_{t-9})$

$- \underset{(-3.02)}{110.60}*T)*(D1+D2+D4)$

$+ (\underset{(1.29)}{21.54}*(FP_{S,t-2}+FP_{S,t-3}+FP_{S,t-4}+FP_{S,t-5})/4) + \underset{(3.27)}{0.039}*(CC_{t-6}+CC_{t-7}+CC_{t-8}+CC_{t-9})$

$- \underset{(-2.15)}{9.063}*((FC_{F,t-2}+FC_{F,t-3}+FC_{F,t-4}+FC_{F,t-5})/4) - \underset{(-1.48)}{1.63}*(I_D - I_{D,t-1}) - 60.18*T)*D3$

$+ \underset{(3.19)}{0.43}\rho_{t-1} + \underset{(2.79)}{0.35}\rho_{t-4}$

$R^2 = 0.81 \qquad DW = 1.96$

(6) $I_{DC} = I_C + HA_{t-1} + DL_{DC,t-1} + CS_{DC,t-1}$

(7) $CC = \underset{(193.00)}{0.33}*I_{DC}*D1 + \underset{(178.00)}{0.31}*I_{DC}*D2 + \underset{(44.20)}{0.08}*I_{DC}*D3 + \underset{(107.00)}{0.18}*I_{DC}*D4 + \underset{(7.96)}{0.622}\rho_{t-1}$

$R^2 = 0.99 \qquad DW = 1.99$

(8) $I_B = I_{B,t-1} + CC_{t-1} + LI_{B,t-1} + LX_{B,t-1} - CS_{SH,t-1} - CS_{L,t-1} - FS_{B,t-1} - CS_{DC,t-1} - CS_{BS,t-1}$

(9) $FL = (CC_{t-2}+CC_{t-3}+CC_{t-4})/(1 + \exp(\underset{(36.00)}{2.09} - \underset{(-5.98)}{0.50}*(FP_S/FC_F) - \underset{(-3.56)}{0.0003}*LI_B - \underset{(-6.31)}{0.33}*D2$

$- \underset{(-8.85)}{0.46}*D3 - \underset{(-5.12)}{0.26}*D4))$

$R^2 = 0.65 \qquad DW = 1.09$

(10) $CS_F = I_F/(1 + \exp(\underset{(-6.94)}{-1.12} + \underset{(7.74)}{0.00012}*I_{F,t-1} - \underset{(-2.53)}{0.24}*(FP_S/FC_F) - \underset{(-6.71)}{0.34}*D2 - \underset{(-8.35)}{0.40}*D3 - \underset{(-5.12)}{0.26}*D4))$

$R^2 = 0.40 \qquad DW = 1.09$

Table 2. (continued)

(11) $$CS_N = I_N/(1 + \exp(\underset{(3.57)}{5.03} - \underset{(-1.12)}{0.00005}(I_B - I_{DC} - CC - CC_{t-1} - CC_{t-2} - CC_{t-3}) + \underset{(1.30)}{0.012}*FP_S - \underset{(-2.55)}{0.31}*D2 - \underset{(-0.89)}{0.14}*D3 - \underset{(-0.30)}{0.09}*D4))$$

$R^2 = 0.80 \qquad DW = 2.12$

(12) $I_F = I_{F,t-1} + FL_{t-1} - CS_{F,t-1}$

(13) $I_N = I_{B,} - I_F - I_{DC}$

(14) $CS_{SH} = CS_F + CS_N$

(15) $$CW_B = \underset{(-0.99)}{-13.608}*(FP_S/FC_B)_{t-1} - \underset{(-2.46)}{1.13}*IN + \underset{(3.13)}{4.78}*T + \underset{(20.40)}{574.27}*D1 + \underset{(20.30)}{575.23}*D2 + \underset{(20.10)}{569.17}*D3 + \underset{(20.10)}{568.5}*D4 + \underset{(13.20)}{0.84}\rho_{t-1}$$

$R^2 = 0.81 \qquad DW = 1.98$

(16) $SP_B = (CW_B*(CS_{SH}+CS_{DC}))/1000$

(17) $TS_B = SP_B + SF_B + IM_B + BS_B$

(18) $TD_B = TS_B - EX_B - ES_B$

(19) $PC_B = (TD_B/POP)*CV_B$

**Pork Supply Sector**

(20) $FC_P = (378.2/56)*PG + (106.54/2000)*PM$

(21) $$GA = \underset{(2.12)}{904.33} + \underset{(0.23)}{0.0017}*I_{BG} + \underset{(0.819)}{15.26}*((FP_{BG}/FC_P)+(FP_{BG}/FC_P)_{t-1}+(FP_{BG}/FC_P)_{t-2}+(FP_{BG}/FC_P)_{t-3}) - \underset{(-1.21)}{2.45}*(IN+IN_{t-1}+IN_{t-2}+IN_{t-3}) - \underset{(-0.32)}{2.95}*T + \underset{(1.66)}{106.19}*D769 + \underset{(1.76)}{149.16}*D2 - \underset{(-1.61)}{130.43}*D3 + \underset{(1.70)}{136.82}*D4$$

$R^2 = 0.28 \qquad DW = 2.08$

(22) $$CS_W = I_W/(1 + \exp(\underset{(11.90)}{1.43} + \underset{(3.95)}{0.12}*((FP_{BG}/FC_P)+(FP_{BG}/FC_P)_{t-1}) + \underset{(0.44)}{0.0014}*(IN+IN_{t-1}) + \underset{(4.64)}{0.14}*D2 - \underset{(-2.38)}{0.08}*D3 - \underset{(-4.88)}{0.13}*D4)) + \underset{(8.83)}{0.78}\rho_{t-1}$$

$R^2 = 0.75 \qquad DW = 2.07$

(23) $I_W = I_{W,t-1} + GA_{t-1} - CS_{W,t-1}$

(24) $$PC = \underset{(20.40)}{2.05}*I_W*D1 + \underset{(28.60)}{2.67}*I_W*D2 + \underset{(23.60)}{2.30}*I_W*D3 + \underset{(22.80)}{2.31}*I_W*D4 + \underset{(5.40)}{1901.30}*(FP_{BG}/FC_P)$$

$R^2 = 0.47 \qquad DW = 0.22$

Table 2. (continued)

(25) $CS_{BG} = -927.02 + 0.40*I_{BG} - 61.54*((FP_{BG}/FP_P)+(FP_{BG}/FP_P)_{t-1}+(FP_{BG}/FP_P)_{t-2})$
(-0.69) (17.80) (-0.85)
$+ 59.83*(IN+IN_{t-1}+IN_{t-2}) + 2507.50*D2 - 1011.40*D3 + 832.08*D4$
(11.00) (8.71) (-3.66) (3.03)

$R^2 = 0.86$ DW = 1.00

(26) $I_{BG} = I_{BG,t-1} + PB_{t-1} - GA_{t-1} - CS_{BG,t-1} - DL_{P,t-1} + LI_{P,t-1} - LX_{P,t-1}$
(27) $LW_{BG} = 2.65*(FP_{BG}/FC_P)_{t-1} - 0.09*IN_{t-1} + 229.77*D1 + 231.35*D2$
(2.81) (-0.871) (22.50) (22.60)
$+ 227.97*D3 + 229.70*D4 + 0.36*TIME + 0.89\rho_{t-1}$
(22.30) (22.40) (0.72) (11.20)

$R^2 = 0.71$ DW = 2.12

(28) $LW_W = 452.29*D1 + 453.43*D2 + 442.91*D3 + 442.63*D4 + 7.23*(FP_{BG}/FC_P) + 0.87\rho_{t-1}$
(62.00) (63.30) (60.20) (60.00) (3.07) (14.50)

$R^2 = 0.77$ DW = 1.76

(29) $LS_P = (LW_W*CS_W + LW_{BG}*CS_{BG})/1000$
(30) $SP_P = LS_P*LV_P$
(31) $TS_P = SP_P + SF_P + BS_P + IM_P$
(32) $TD_P = TS_P - EX_P - ES_P$
(33) $PCC_P = TD_P/POP$
(34) $PC_P = PCC_P*CV_P$

**Chicken Supply Sector**

(35) $FC_K = (1.4/56)*PG + (0.6/2000)*PM$
(36) $KL = -604.99 + 0.01*KH_{t-2} + 44.585*(FP_K/FC_K) - 32.33*IN - 92.95*T$
(-0.58) (5.15) (1.21) (-2.09) (-1.03)
$+ 2025.60*D2 + 317.97*D3 - 741.38*D4$
(6.76) (1.35) (-3.03)

$R^2 = 0.84$ DW = 0.81

(37) $KH = 132713.0 + 45.92*KL_{t-1} + 538.13*FP_K + 27099.0*T$
(5.20) (13.30) (1.13) (21.80)
$+ 81334.0*D2 - 22003.0*D3 - 62010.0*D4$
(8.72) (-2.08) (-6.68)

$R^2 = 0.98$ DW = 1.39

(38) $FS_Y = 61001.0 + 0.75*KH_{t-1} + 7813.90*T + 38063.0*D2 - 5405.60*D3 - 47473.0*D4$
(4.9) (21.70) (5.53) (6.78) (-0.74) (-7.61)

$R^2 = 0.99$ DW = 1.92

Table 2. (continued)

(39) $LW_Y$ = 3.36 + 0.04*T - 0.02*D2 - 0.11*D3 - 0.01*D4
(203.0) (49.2) (-1.50) (-9.28) (-1.16)

$R^2$ = 0.97 DW = 0.92

(40) $LS_Y$ = $FS_Y$*$LW_Y$
(41) $SP_Y$ = 4835.0 + 0.72*$LW_Y$ + 10189.0*D2 + 12989.0*D3 + 11712.0*D4 + 0.88$\rho_{t-1}$
(0.14) (93.6) (3.35) (3.9) (5.71) (13.5)

$R^2$ = 0.99 DW = 2.5

(42) $TS_Y$ = 72314.0 + 0.98*$SP_Y$ + 7274.90*D2 + 7457.0*D3 + 4237.40*D4
(7.49)(322.0) (1.16) (1.19) (0.68)

$R^2$ = 0.99 DW = 0.30

(43) $TS_O$ = 227187.0 - 1576.50*((2*($FP_K$/$FC_K$)+($FP_K$/$FC_K$)$_{t-1}$)/3) - 2010.50*T + 12075.0*D2
(22.6) (-1.89) (-5.21) (2.31)
- 13413.0*D3 - 15988.0*D4
(-2.57) (-3.06)

$R^2$ = 0.45 DW = 0.93

(44) $TD_Y$ = $TS_Y$ + $BS_Y$ - $EX_Y$ - $ES_Y$
(45) $PC_Y$ = ($TD_Y$/POP)/1000
(46) $TD_O$ = $TS_0$ + $BS_O$ - $EX_O$ - $ES_O$
(47) $PC_O$ = ($TD_O$/POP)/1000
(48) $PC_K$ = $PC_Y$ + $PC_O$

**Meat Demand Sector**

(49) $S_B$ = 0.47 + 0.01*D2 + 0.015*D3 - 0.003*D4 + 0.133*ln($PC_B$)
(11.44)(0.66) (1.11) (-0.30) (6.09)
- 0.060*ln($PC_P$) - 0.0533*ln($PC_K$) - 0.019*ln($PC_T$)
(-4.22) (-4.15) (-4.21)
+ 0.003*(1 + ( 0.47*D1 + 0.010*D2 - 0.015*D3 - 0.003*D4)*ln($PC_B$)
(0.51) (11.44) (0.66) (1.11) (-0.30)
+ ( 0.328*D1 - 0.017*D2 - 0.024*D3 - 0.010*D4)*ln($PC_P$)
(10.66) (-1.67) (-2.55) (-1.25)
+ ( 0.188*D1 - 0.004*D2 - 0.004*D3 - 0.013*D4)*ln($PC_K$)
(6.02) (-0.39) (-0.42) (-1.49)
+ ( 0.018*D1 + 1.01*D2 + 1.01*D3 + 1.03*D4)*ln($PC_T$)
+ 0.133*ln($PC_B$)*ln($PC_B$) + 0.074*ln($PC_P$)*ln($PC_P$) + 0.058*ln($PC_K$)*ln($PC_K$)
(2.43) (4.58) (3.44)
+ 0.009*ln($PC_T$)*ln($PC_T$) - 0.06*ln($PC_B$)*ln($PC_P$) - 0.053*ln($PC_B$)*ln($PC_K$)
- 0.015*ln($PC_P$)*ln($PC_K$) - 0.019*ln($PC_B$)*ln($PC_T$) + 0.0007*ln($PC_P$)*ln($PC_T$)
(-1.31)
+ 0.010*ln($PC_K$)*ln($PC_T$) + 0.817$\rho_{t-1}$
(15.7)
$R^2$ = 0.92 DW = 1.815

Table 2. (continued)

(50) $S_P$ = 0.328 - 0.017*D2 - 0.024*D3 - 0.010*D4 - 0.060*ln($PC_B$)
(10.70) (-1.67) (-2.55) (-1.25) (-4.22)
\+ 0.074*ln($PC_P$) - 0.015*ln($PC_K$) - 0.0007*ln($PC_T$)
(4.58) (-1.13)
\- 0.006*(1 + ( 0.47*D1 + 0.009*D2 - 0.15*D3 - 0.003*D4)*ln($PC_B$)
(-1.25) (11.44) (0.66) (1.11) (-0.30)
\+ (0.328*D1 - 0.017*D2 - 0.024*D3 - 0.010*D4)*ln($PC_P$)
(10.66) (-1.67) (-2.55) (-1.25)
\+ (0.188*D1 - 0.004*D2 - 0.004*D3 - 0.013*D4)*ln($PC_K$)
(6.02) (-0.39) (-0.42) (-1.49)
\+ (0.018*D1 + 1.01*D2 + 1.01*D3 + 1.03*D4)*ln($PC_T$)
\+ 0.133*ln($PC_B$)*ln($PC_B$) + 0.074*ln($PC_P$)*ln($PC_P$) + 0.058*ln($PC_K$)*ln($PC_K$)
(2.43) (4.58) (3.44)
\+ 0.009*ln($PC_T$)*ln($PC_T$) - 0.06*ln($PC_B$)*ln($PC_P$) - 0.053*ln($PC_B$)*ln($PC_K$)
\- 0.015*ln($PC_P$)*ln($PC_K$) - 0.019*ln($PC_B$)*ln($PC_T$) + 0.0007*ln($PC_P$)*ln($PC_T$)
(-1.31)
\+ 0.010*ln($PC_K$)*ln($PC_T$)) + 0.817$\rho_{t-1}$
(15.7)
$R^2$ = 0.75 DW = 1.83

(51) $S_K$ = 0.188 - 0.004*D2 - 0.003*D3 - 0.013*D4 - 0.053*ln($PC_B$)
(6.02) (-0.39) (-4.19) (-1.49) (-4.15)
\- 0.015*ln($PC_P$) + 0.058*ln($PC_K$) - 0.009*ln($PC_T$)
(-1.13) (3.44)
\- 0.004*(1+ ( 0.47*D1 + 0.009*D2 - 0.15*D3 - 0.003*D4)*ln($PC_B$)
(0.87)
\+ (0.328*D1 - 0.017*D2 - 0.024*D3 - 0.010*D4)*ln($PC_P$)
(10.66) (-1.67) (-2.55) (-1.25)
\+ (0.188*D1 - 0.004*D2 - 0.004*D3 - 0.013*D4)*ln($PC_K$)
(6.02) (-0.39) (-0.42) (-1.49)
\+ (0.018*D1 + 1.01*D2 + 1.01*D3 + 1.03*D4)*ln($PC_T$)
\+ 0.133*ln($PC_B$)*ln($PC_B$) + 0.074*ln($PC_P$)*ln($PC_P$) + 0.058*ln($PC_K$)*ln($PC_K$)
(2.43)
\+ 0.009*ln($PC_T$)*ln($PC_T$) - 0.06*ln($PC_B$)*ln($PC_P$) - 0.053*ln($PC_B$)*ln($PC_K$)

\- 0.015*ln($PC_P$)*ln($PC_K$) - 0.019*ln($PC_B$)*ln($PC_T$) + 0.0007*ln($PC_P$)*ln($PC_T$)
(-1.31)
\+ 0.010*ln($PC_K$)*ln($PC_T$)) + 0.817$\rho_{t-1}$

$R^2$ = .91 DW = 1.40

Table 2. (continued)

(52) $S_T = 1 - S_B - S_P - S_K$
(53) $R_B = (S_B*XM)/PC_B$
(54) $R_P = (S_P*XM)/PC_P$
(55) $R_K = (S_K*XM)/PC_K$
(56) $R_T = (S_T*XM)/PC_T$

**Pork Margin Specification**

(57) $NSP_P = SP_P/POP$
(58) $NR_P = (R_P*100)/CPI$
(59) $NM_p = \underset{(14.5)}{0.57*NR_P*D1} + \underset{(13.9)}{0.56*NR_P*D2} + \underset{(15.0)}{0.57*NR_P*D3} + \underset{(13.70)}{0.56*NR_P*D4}$

$+ \underset{(5.42)}{0.014*NR_P*NSP_P} - \underset{(-0.32)}{0.018*MK} - \underset{(-7.09)}{2.03*BY_P} + \underset{(11.3)}{0.88\rho_{t-1}}$

$R^2 = 0.98$ DW = 2.42

(60) $FP_{BG} = (NR_P - NM_P)*CPI$

**Beef Margin Specification**

(61) $NSP_B = SP_B/POP$
(62) $NR_B = (R_B*100)/CPI$
(63) $NM_B = \underset{(11.2)}{0.58*NR_B*D1} + \underset{(11.1)}{0.57*NR_B*D2} + \underset{(10.9)}{0.57*NR_B*D3} + \underset{(10.8)}{0.57*NR_B*D4}$
$+ \underset{(5.47)}{0.008*NR_B*NSP_B} + \underset{(0.12)}{0.01*MK} - \underset{(-4.03)}{0.69*BY_B} + \underset{(18.7)}{0.92\rho_{t-1}}$

$R^2 = 0.98$ DW = 2.14

(64) $FP_S = (NR_B - NM_B)*CPI$

**Chicken Margin Specification**

(65) $NTS_Y = (TS_Y/POP)/1000$
(66) $NTS_O = (TS_O/POP)/1000$
(67) $NR_K = (R_K*100)/CPI$
(68) $NM_K = \underset{(3.8)}{0.06*NR_K*D1} + \underset{(3.28)}{0.05*NR_K*D2} + \underset{(3.1)}{0.04*NR_K*D3} + \underset{(5.63)}{0.09*NR_K*D4}$

$+ \underset{(3.63)}{0.005*(NTS_Y+NTS_O)*NR_K} + \underset{(1.32)}{0.014*MP} + \underset{(9.04)}{0.52*LAG(NM_K)}$

(69) $FP_K = (NR_K - NM_K)*CPI$

Table 2. (continued)

**Grain Consuming Identities**

(70) $GC_D = I_D/1000$
(71) $GC_C = (0.0095*I_C + 0.017*HA)/1000$
(72) $GC_F = (0.48*FL + 0.89*FL_{t-1} + 0.49*I_F)/1000$
(73) $GC_W = (0.551*I_W)/1000$
(74) $GC_{BG} = ((0.598*(I_{BG} - PC)) + 0.497*PC)/1000$
(75) $GC_K = (0.0102*CS_Y + 0.0142*CS_O)/1000$
(76) $GC = GC_D + GC_C + GC_F + GC_W + GC_{BG} + GC_K$

**High Protein Identities**

(77) $HP_D = I_D/1000$
(78) $HP_C = (0.0033*I_C + 0.016*HA)/1000$
(79) $HP_F = (0.40*FL + 0.44*FL_{t-1} + 0.11*I_F)/1000$
(80) $HP_W = (0.398*I_W)/1000$
(81) $HP_{BG} = ((0.429*(I_{BG} - PC)) + 0.359*PC)/1000$
(82) $HP_K = (0.0165*CS_Y + 0.0137*CS_O)/1000$
(83) $HP = HP_D + HP_C + HP_F + HP_W + HP_{BG} + HP_K$

**Reduced form crop prices**

(84) PG $= \underset{(-0.36)}{-1.056} + \underset{(1.74)}{0.079}*(GC_{t-1} + GC_{t-2} + GC_{t-3} + GC_{t-4})/4$

$- \underset{(-1.15)}{0.059}*(CBR_{t-1} + CBR_{t-2} + CBR_{t-3} + CBR_{t-4}))/4$

$- \underset{(-1.74)}{0.057}*T + \underset{(0.90)}{0.05}*D1 + \underset{(2.05)}{0.134}*D2 + \underset{(3.33)}{0.186}*D3 + \underset{(12.00)}{0.87}\rho_{t-1}$

(85) PM $= \underset{(-0.30)}{-46.55} + \underset{(2.10)}{6.63}*(HP_{t-1} + HP_{t-2} + HP_{t-3} + HP_{t-4})/4$

$- \underset{(-3.58)}{14.79}*(CBR_{t-1} + CBR_{t-2} + CBR_{t-3} + CBR_{t-4}))/4$

$- \underset{(-0.24)}{0.052}*T - \underset{(-0.34)}{1.93}*D1 - \underset{(-0.19)}{1.21}*D2 - \underset{(-0.01)}{0.04}*D3 + \underset{(5.25)}{0.61}\rho_{t-1}$

Equation 7 represents the calf crop. This equation is estimated as a function of cow inventory only. There is no direct inclusion of economic variables, since once the cow is bred, it is not likely that the producer will terminate the pregnancy of the cow; thus, calf crop is largely predetermined. As expected, the coefficients very closely represent the proportions of calves born in respective quarters throughout the year. This further illustrates why heifer additions are highly seasonal.

Equation 8 provides a representation of the total inventory of cattle and calves. This is the basic stock identity for the entire beef supply system. The key flow variables for this identity include calves born, live cattle imports, live cattle exports, steer and heifer slaughter, calf slaughter, on-farm slaughter, cow slaughter, death loss, and bull and stag slaughter. The only flow variable which remains to be estimated is steer and heifer slaughter. The rest are not estimated because they represent very small components of the production process. Steer and heifer slaughter (the remaining flow variable) is not straight-forward. Steers and heifers marketed are separated into two groups: fed cattle and non-fed cattle. The inventory of fed beef is the category of beef for which data is available, and results in the majority of beef production. This portion of the separation of steers and heifers is specified and non-fed cattle are determined as a residual. Equation 9 is the estimated equation for cattle placed on feed. The placements equation is specified as a logistic function and bounded by calf crops lagged two, three, and four periods. The lags represent the population of calves which are available for placement on feed. Since placements from this pool can be made at any time; the current steer price and feed costs are significant in affecting current placement decisions. Live imports are included since many of these animals may also be placed on feed when they arrive.  The other flow variable in the fed cattle component is fed cattle slaughter (Equation 10). Again, this is specified as a logistic function and restricted by the inventory of fed cattle. Estimation of placements on feed and fed slaughter provides the flow variables for constructing the identity of the inventory of cattle on feed (Equation 12).  This leaves the determination of non-fed cattle inventory as a residual of total inventory of cattle and calves less cattle on feed and cow inventory (Equation 13).  However, it is still necessary to estimate non-fed slaughter to determine total slaughter of steers and heifers, which determines the majority of beef production. Non-fed slaughter is estimated as a logistic function bounded by the inventory of non-fed cattle (Equation 11).  Slaughter of steers and heifers is simply fed slaughter plus non-fed slaughter (Equation 14).

The only remaining equation necessary to determine beef production is the average carcass weight of cattle.  While carcass weights vary between types of animals (e.g., fed steers vs. cows), the data is not available to make this distinction and an average carcass weight is used as a proxy. Equation 15 provides the specification for this equation.  Intuition suggests that the sign of the price/feed cost coefficient should be positive.  However, because the proportion of cattle represented by cows and non-fed cattle increases during lower prices and they have lower carcass weights than fed cattle, this sign is consistent.

Equations 16-19 are necessary identities to derive per-capita beef consumption (Equation 19), which is the end product of beef production in this disappearance framework.  Total beef production (Equation 16) is the average carcass weight multiplied by total slaughter as represented by steer and heifer slaughter and cow slaughter.  Total beef supply (Equation 17) is comprised of total production plus beginning stocks plus on-farm production plus beef imports. Total domestic disappearance (Equation 18) is total beef supply less beef exports and ending stocks. Per capita consumption (Equation 19) is simply total disappearance divided by population and multiplied by the carcass weight to retail weight conversion factor (0.71). This conversion factor is specified by the USDA and is relatively constant over time.

### Pork supply structure

As with beef, it is first necessary to develop the feed cost variable for inclusion in the pork supply sector. The feed cost for pork (Equation 20) is composed of corn and soymeal, which are the two primary ingredients in standard hog feed rations. The prices are weighted by the proportion of the type of feed in the ration.

The structure of the pork supply system is very similar to the beef supply sector. Economic variables affecting decisions on culling and additions to the breeding herd largely determine future pork production. Equation 21 represents gilt additions to the breeding herd. The lag structure is determined by the time lag from the decision to retain a gilt and for the gilt to farrow, which is the time it enters the breeding herd. Equation 22 represents sow slaughter or culling decision. The sow slaughter equation is estimated as a logistic function bounded by the current breeding herd inventory. Because the decision to cull a sow requires less time than the decision to add a gilt and farrow, the lag structure is shorter. The lag structure is two periods to allow for the fact that any sows currently bred will be allowed to farrow and wean their piglets. The equations for sow slaughter and particularly gilt retention, do not explain a high proportion of the variance. This may be due to the omission of an age of herd variable, which would likely add significant explanatory power to this system; however, this information is not available.

Equation 23 represents the breeding herd inventory identity comprised of gilt additions and sow slaughter. The breeding herd inventory largely determines the subsequent pig crop (Equation 24). The coefficients associated with breeding herd inventory may appear small, but it must be considered that at any given time substantially less than the total breeding herd inventory is farrowing. Thus, these coefficients represent pigs per litter times the proportion of sows in the breeding herd farrowing during that quarter. Pig crop is also a function of current barrow and gilt prices and feed costs. The significant positive coefficient is a function of the increased proportion of the sow herd farrowing during periods of higher prices.

Equation 25 is barrow and gilt slaughter. This is the primary determinant of pork production and is mostly determined by the inventory of barrows and gilts. However, prices and interest rates are included as explanatory variables. The negative coefficient on the price/feed cost variable represents the flow of gilts toward additions to the breeding herd rather than to slaughter.

Equation 26 is the barrow and gilt inventory identity. This identity is composed of the stocks and flows of the pork supply system. The inflows include pig crop and live imports. The outflows include additions to the breeding herd, barrow and gilt slaughter, death loss and live exports. Live imports, live exports and death loss are not estimated within the system. Gilt additions do not represent a terminal flow but, rather, a flow from barrow and gilt inventory to breeding herd inventory.

With slaughter numbers determined, the slaughter weights must be determined to derive total pork production. Barrow and gilt liveweights (Equation 27) and sow liveweights (Equation 28) are estimated and behave as expected--increasing as prices increase. A time trend is included to account for the trend toward larger animals at slaughter.

Equations 29-34 provide the identities necessary to derive per capita pork consumption which is the end result of pork production. Equation 29 determines the total liveweight production of pork and is simply slaughter multiplied by the liveweight of animals in each respective class. Equation 30, commercial pork production, is liveweight production multiplied by a liveweight-carcass conversion factor (0.69). Equation 31 is total pork supply and is determined by adding on-farm pork production, pork beginning stocks, and pork imports to commercial pork production. Equation 32 is total domestic pork disappearance. This is simply total supply less pork exports and pork ending stocks. Equation 33 is the per-capita carcass weight consumption of pork and is obtained by dividing total disappearance by population. Finally, Equation 34 is per capita pork consumption and is per capita carcass weight consumption multiplied by a carcass-retail weight conversion factor (0.78).

## Chicken Supply Sector

The feed cost variable for chicken (Equation 35) is specified in the same manner as for beef and pork. The feed components are corn and soymeal, and these are weighted in the proportion they occur in the ration.

The chicken supply sector is represented by Equations 35-48. There are two classes of chicken production represented. The first and largest is the young chicken or broiler production sector. Broilers account for the majority of chicken production. Other chicken is comprised of mature chickens, such as laying hens from hatchery supply flocks or from egg production.

Unlike beef and pork, the chicken supply sector does not have well defined biological flows. This is mostly because of the rapid turn-around time in the biological production of chickens. Thus, this system does not have well defined inventory identities and is specified as a function of various production flow variables, which help provide some systematic structure to the system.

Hens placed into the hatchery supply flock, Equation 36, represents the decision to increase the production of broilers, since more placements lead to more egg production. This is shown in Equation 37 where chicks hatched is a function of previous placements into the hatchery supply flock. Similarly, federally inspected young chicken slaughter (Equation 38) is a function of previous hatchings because once the birds are hatched they will be grown-out in approximately one quarter. Quarterly lags probably reflect too long a production cycle; however, it is a much better representation than previous annual models and provides at least some ability to maintain biological flows through the system.

Equation 39 provides the average liveweight of young chickens under federally inspected slaughter which is necessary for determining total federally inspected liveweight production (Equation 40). Equation 41 is federally inspected ready-to-cook young chicken production. The coefficient on the variable liveweight represents the conversion factor from liveweight to ready-to-cook weight. Finally, Equation 42 is total young chicken production. The coefficient on federally inspected young chicken slaughter represents the proportion of the total young chicken production, which is made up of federally inspected young chicken. The other 2 percent is chicken, which does not enter commercial poultry slaughter plants.

Equation 43 is a direct estimation of other chicken production. There is little data available for providing any structure to this equation; specifications which included such variables as placements into hatchery supply flock did not improve the statistical properties of the equation. The price coefficient is negative because higher prices result in fewer hens slaughtered as more are kept in hatchery supply flocks.

Equation 44 represents total young chicken consumption. This is simply total young chicken production plus beginning stocks of young chicken less young chicken exports and young chicken ending stocks. Equation 45 represents per capita consumption of young chicken and is simply total young chicken consumption divided by population.

Equation 46 is analogous to Equation 44 but determines total other chicken consumption. This is total other chicken production plus beginning stocks of other chicken less other chicken exports and ending stocks of other chicken. Equation 47 is per-capita consumption of other chicken and is simply total other chicken consumption divided by population. Equation 48 represents total per capita chicken consumption, which is the sum of per capita young chicken consumption and per capita other chicken consumption.

Because of the non-linear specification of the model and the level of disaggregation of supply equations, it is difficult to directly calculate supply flexibilities. As an approximation for the price response, each industry's representative farm prices (slaughter steer, barrow and gilt, and wholesale chicken) were perturbed by 10 percent to determine impacts on production. The results are shown in Table 3.

Table 3. Impact of 10 percent increase in own farm price on supply

| Period | Percent change in beef supply | Percent change in pork supply | Percent change in young chicken supply |
|---|---|---|---|
| -1 | 0.000 | 0.000 | 0.000 |
| 0 | -0.783 | 0.601 | 0.211 |
| 1 | -0.694 | 2.626 | 0.490 |
| 2 | 0.560 | 4.230 | 0.598 |
| 3 | 2.359 | 5.304 | 0.642 |
| 4 | 3.934 | 6.005 | 0.664 |
| 5 | 5.182 | 6.464 | 0.672 |
| 6 | 6.152 | 6.766 | 0.676 |
| 7 | 6.905 | 6.965 | 0.677 |
| 8 | 7.492 | 7.096 | 0.678 |
| 9 | 7.953 | 7.183 | 0.678 |
| 10 | 8.319 | 7.240 | 0.679 |
| 20 | 9.505 | 7.346 | 0.679 |

The results in Table 3 seem reasonable based on prior expectations. The chicken price response is very low in this model. This is largely because of the lack of a readily identifiable price to which broiler production responds and because of the lack of an explicit biological structure. However, previous supply models of the broiler industry (Chavas and Johnson 1982; Jensen et al. 1989) have also obtained these low price responses.

Meat Demand Sector

Beef, pork, chicken, and turkey are included in the demand system. These comprise the major portion of meat consumption in the U.S.. The meat group (i.e., beef, pork, chicken and turkey) is assumed to be weakly separable from other goods and other foods. In addition, homogeneity, symmetry and adding up restrictions were imposed on the system. Homogeneity, symmetry and adding up restrictions were not specifically tested, but their imposition resulted in much improved estimation results, and are maintained hypotheses.

Equations 49-51 in Table 2 provide the estimated coefficients and t-statistics for the demand system estimated using iterative three-stage-least-squares (IT3SLS). The turkey equation is omitted to avoid singularity, and the implied coefficients for the turkey share equation are derived from the imposed restrictions. The majority of the coefficients are significant and of the proper sign. However, the coefficients of the scale effect are not significant for this representation. The scale effect was left in its quadratic form. In addition, to achieve invariance to the equation deleted, the technique of using the same correlation coefficient for each equation is used (Berndt and Savin 1975).

Of primary interest are the flexibilities associated with the estimated demand system (Table 4). The uncompensated flexibilities are reasonable, and all own-price and cross-price flexibilities indicate gross substitutability between the meats, except for some of the turkey flexibilities. This is likely a result of the strong seasonality associated with turkey consumption. The scale effects are also of proper sign and reasonable magnitude. The compensated flexibilities indicate that all goods are net substitutes, except for chicken and turkey.

The flexibilities of three other studies, which estimate inverse demand systems for meat (Dahlgran 1987; Huang 1988; and Eales and Unnevehr 1991) are provided in

Table 5. Because of differences in estimation procedures, commodities included, and system specifications used, the results are not directly comparable across the studies. However, the estimated flexibilities provide a range of values and magnitudes which are approximate to the values provided in this study. Not all studies included scale flexibilities, and so they are not included. Also, the variability of scale flexibilities are sensitive to the commodities included in the system estimation. Since none of the models include the same set of commodities, the scale flexibilities are not comparable. An additional study by Anderson and Wilkinson (1985) provides similar low flexibilities.

## Pork Margin

While Wohlgenant and Mullen examined the beef farm-retail margin relationship, no studies have explicitly examined this relationship for pork. Data required for the specification includes quarterly farm and retail prices, a packer cost index, commercial pork production, and value of pork byproducts.

The margin equation provides a link between the retail price, which is determined in the demand model, and the farm price. Thus, the margin is directly calculated as the retail price minus the farm price in cents per pound. This allows the nominal margin to be calculated directly from the available data. One problem with this specification is that the farm price represents the value of the whole animal; whereas the retail price represents the value of the retail yield of the carcass. In general, this is reconciled by weighting the farm price by some conversion factor of farm quantity to retail quantity.

Table 4. Demand system flexibilities

| | Beef | Pork | Chicken | Turkey | Scale |
|---|---|---|---|---|---|
| | | Uncompensated flexibilities | | | |
| Beef | -0.773 | -0.104 | -0.092 | -0.032 | -1.01 |
| Pork | -0.214 | -0.713 | -0.051 | 0.003 | -0.98 |
| Chicken | -0.394 | -0.103 | -0.544 | 0.075 | -0.97 |
| Turkey | -0.670 | -0.037 | 0.252 | -0.751 | -1.21 |
| | | Compensated flexibilities | | | |
| Beef | -1.348 | -0.374 | -0.224 | -0.068 | |
| Pork | -0.773 | -0.972 | -0.177 | -0.031 | |
| Chicken | -0.948 | -0.359 | -0.669 | 0.042 | |
| Turkey | -1.361 | -0.357 | 0.096 | -0.792 | |

Table 5. Summary of estimated flexibilities by different studies

| Study | Data | Period | Demand specification | Own price[a] | Cross price[b] |
|---|---|---|---|---|---|
| Dahlgran (1987) | Annual | 1950-1985 | Rotterdam | B -1.069<br>P -1.243<br>C -1.184 | BP -.273 BC -.071<br>PB -.460 PC -.156<br>CB -.268 CP -.400 |
| Huang (1988) | Annual | 1947-1983 | Rotterdam | B -1.082<br>P -1.222<br>L -1.059 | BP -.052 BL -.135<br>PB -.066 PL -.102<br>LB -.468 LP -.279 |
| Eales and Unnevehr (1991) | Quarterly | 1966-1988 | IAIDS | B -0.947<br>P -0.990<br>C -0.755 | BP -.173 BC -.180<br>PB -.351 PC -.318<br>CB -.930 CP -.899 |

[a] B = Beef, P = Pork, C = Chicken, L = Poultry
[b] BP = Beef/Pork, BC = Beef/Chicken, BL = Beef/Poultry, PB = Pork/Beef, PC = Pork/Chicken , PL = Pork/Poultry, CB = Chicken/Beef, CP = Chicken/Pork, LB = Poultry/Beef LP = Poultry/Pork.

However, in a regression context this should be implicit in the coefficient on the retail price such that one would expect the coefficient to be less than one. In addition, one may account for margin changes by including the value of byproducts. It is expected that as the value of the byproducts increases, the margin should narrow since the carcass is worth more given a constant retail price with an increase in the byproduct value. The data for the estimation of the farm-retail margin is the seven-market barrow and gilt price ($/cwt.), the average retail price of pork (cents/pound), value of pork byproducts (cents/pound), commercial pork production (mill. pounds), and a processor cost index (1982=100). For estimation purposes all prices are normalized by the consumer price index (1982=100), and commercial pork production is expressed on a per capita basis. The processor cost index is a simple average of an index of meat packers' wage rates and a producer price of fuel and power index (1982=100).

Equation 59 in Table 2 is the estimated pork margin. This specification is very similar to Wohlgenant and Mullen's specification for the beef margin, but because the actual farm and retail price were used in calculating the margin, the value of pork byproducts was added to the specification. In addition, the specification included quarterly dummy variables to account for seasonal variation, and it was necessary to correct for autocorrelation. The coefficient on the processing cost index term is negative, but not significant. Intuition suggests that as marketing costs increase, the margin should increase as processors and retailers attempt to reclaim these costs. The index created was heavily influenced by beef packer costs and may not provide a reasonable index of pork processor costs. As expected, the value of the coefficient on pork byproducts is negative and significant. It seems reasonable that as the value of pork byproducts increases, the overall value of the carcass increases, and the processor is able to pass this on to the farm price. The remainder of the equations are identities to establish the margin relationship and barrow and gilt price.

Beef Margin

Essentially the same procedures for developing the pork margin were used in developing the beef margin (Equation 63). All variables are completely analogous to those used in the estimation of the pork margin equation. All coefficients on the beef margin equation have the expected signs. However, the marketing cost coefficient is not significant. It was again necessary to correct for autocorrelation.

Chicken Margin

The estimation of the chicken margin specification proceeds in much the same way as for pork and beef (Equation 68). However, the market cost index for chicken is different. Since the costs of the highly integrated poultry processing industry are quite different from the meat packing industry, the hourly wage rate for poultry processing plants was used in the market cost index rather than the hourly wage rate for meat processing. If the wage rates within the meat processing industry and the poultry processing industry are compared, the real wage rate for meat processing has declined substantially in recent years, while the real wage rate for poultry processing has remained almost constant. An additional difference is that the value of poultry by-products is not available, and is not included in the model.

Reduced Form Feed Demand Specification

It is important to include some feedback to the feed grain and soymeal sector, because changes in production technology in the livestock sector will have impacts on feed grain demand and, hence, feed prices which will affect livestock production through the feed cost variables.

The first step to determination of the feed sector is to develop a measure of feed use by the livestock sector. This is completed by specifying technical relationships of feed usage. Since biological processes determine feed use for different classes of animals, it is necessary to normalize the feed use into representative units. The relationships specified are grain-consuming animal units and high protein animal units. Grain-consuming animal units are the technical index of feed grains used by livestock and poultry. High protein animal units are the technical index of oilseeds (soymeal) used by livestock and poultry. The technical relationships are derived from Lawrence (1985). Equations 70-83 in Table 2 provides the definitions of grain-consuming and high protein animal units by animal class. Each type of animal within the production sector estimated is represented in the GCAU/HPAU system. The technical coefficients represent the amount of feed consumed relative to one dairy cow. This is why the coefficient on the dairy cow portion is simply 1. These equations are the primary linkage between the livestock production sector and the feed sector. As the number of animals increase more feed is consumed, but as the proportions of animal types within the livestock production sector changes, there may be relatively more impact on the grain-consuming or high protein animal units depending on the type of animals. Grain-consuming animal units primarily represent animals consuming feed grains, while high protein animal units primarily represent animals consuming oilseeds high in protein.

Given the feed consumption equations based on technical coefficients, the next step is to estimate reduced form feed price equations, which then link directly to the livestock supply sector through feed prices. For simplicity, the feed price equations are estimated as simple linear equations using OLS. In addition to the demand for feeds represented by GCAUs and HPAUs, average rainfall for the corn belt was included as an explanatory variable to account for some of the supply variability. The system was estimated with a four-quarter lag on each explanatory variable, and the results are shown in Equations 84 and 85.

## Model Validation

The RMSPE and Theil statistics are standard output of the SAS nonlinear simulation procedure (SIMNLIN). The RMSPE measures the deviation, in percentage terms, of the simulated variable from its actual time path (Pindyck and Rubinfeld 1976, p. 362). The Theil statistics include the bias proportion (UM), the regression proportion (UR), and the disturbance proportion (UD) of the decomposition of the mean squared error (MSE), (Maddala 1977, pp. 344-347). The RMSPE and Theil statistics are shown in Table 6. U and U1 (Table 6) are statistics defined as Theil's inequality coefficient and adjusted Theil's inequality coefficient, respectively. These expressions represent a composite of UR, UM, and UD (Pindyck and Rubinfeld 1976, p. 364). The reported simulation statistics appear to be quite acceptable for a dynamic simulation model of this size.

The simulation statistics do not provide insight into the model dynamics or response of the model to exogenous shocks. Dynamic multipliers measure the dynamic response of the model to changes of the exogenous assumption of the model and provide an indication of the stability of the simulation model over time. The first period multipliers are the impact multipliers, which measure the initial impact of the change. The sums of the dynamic multipliers over a period of time are the total long run multipliers (Pindyck and Rubinfeld 1976, p. 392). To illustrate, the corn price is an exogenous variable which affects all livestock sectors. The dynamic multipliers are calculated by simulating the impacts of a 10 percent increase in corn price. The results of the impacts on key variables for a 24-year period are provided in Table 7.

The dynamic multipliers reported (Table 7) are annual averages of the quarterly response. Averaging eliminates seasonal variation and provides a clearer representation of the impacts. A 10 percent increase in the corn price causes beef production and consumption to decline by about 1 percent. Meanwhile, because of the decreased production, both farm and retail prices increase as expected. These magnitudes also appear to be reasonable. The same types of impacts are evident in pork although in greater magnitude. This is likely because the feed cost specification used for beef cow slaughter is not as responsive to corn price changes. The dynamic multipliers indicate that broiler production increases because the demand effects (i.e., price increases) outweigh the negative supply effects. Overall, the dynamic multipliers indicate that the model is dynamically stable. The corn price shock to the model caused the endogenous variables to move in a satisfactory direction and then to return to equilibrium in a cyclical, but stable, pattern.

Table 6. RMPSE and Theil statistics

| Variable | RMSPE | BIAS (UM) | REG (UR) | DIST (UD) | VAR (US) | COVAR (UC) | U1 | U |
|---|---|---|---|---|---|---|---|---|
| CC | 4.8968 | 0.001 | 0.003 | 0.997 | 0.000 | 0.999 | 0.0479 | 0.0239 |
| HA | 19.2955 | 0.016 | 0.015 | 0.969 | 0.023 | 0.962 | 0.1676 | 0.0833 |
| $CS_{DC}$ | 22.9704 | 0.003 | 0.326 | 0.671 | 0.027 | 0.970 | 0.2268 | 0.1123 |
| $I_{DC}$ | 5.4111 | 0.000 | 0.081 | 0.919 | 0.004 | 0.996 | 0.0554 | 0.0277 |
| $I_N$ | 4.5326 | 0.097 | 0.075 | 0.828 | 0.198 | 0.705 | 0.0485 | 0.0244 |
| $I_F$ | 9.0060 | 0.005 | 0.171 | 0.824 | 0.000 | 0.995 | 0.0869 | 0.0433 |
| FL | 10.7871 | 0.000 | 0.037 | 0.963 | 0.015 | 0.985 | 0.1036 | 0.0518 |
| $CS_F$ | 7.7744 | 0.000 | 0.180 | 0.819 | 0.090 | 0.910 | 0.0754 | 0.0377 |
| $CS_N$ | 160.019 | 0.074 | 0.068 | 0.858 | 0.385 | 0.541 | 0.3920 | 0.2186 |
| $CS_{SH}$ | 6.9062 | 0.030 | 0.350 | 0.620 | 0.011 | 0.958 | 0.0693 | 0.0348 |
| $CW_B$ | 2.3779 | 0.000 | 0.185 | 0.815 | 0.482 | 0.518 | 0.0231 | 0.0115 |
| $I_B$ | 3.4108 | 0.034 | 0.081 | 0.885 | 0.219 | 0.747 | 0.0363 | 0.0182 |
| $SP_B$ | 7.3804 | 0.006 | 0.459 | 0.535 | 0.000 | 0.994 | 0.0745 | 0.0374 |
| $TS_B$ | 8.6298 | 0.006 | 0.549 | 0.445 | 0.015 | 0.979 | 0.0872 | 0.0437 |
| $TD_B$ | 7.9291 | 0.006 | 0.545 | 0.449 | 0.009 | 0.985 | 0.0805 | 0.0404 |
| $PC_B$ | 7.9291 | 0.004 | 0.320 | 0.675 | 0.025 | 0.970 | 0.0814 | 0.0408 |
| $FP_C$ | 14.4371 | 0.030 | 0.105 | 0.865 | 0.003 | 0.967 | 0.1332 | 0.0658 |
| $CS_W$ | 13.8485 | 0.001 | 0.008 | 0.991 | 0.134 | 0.865 | 0.1351 | 0.0680 |
| $I_W$ | 10.1095 | 0.000 | 0.051 | 0.949 | 0.514 | 0.486 | 0.1017 | 0.0510 |
| GA | 23.1455 | 0.000 | 0.000 | 1.000 | 0.290 | 0.710 | 0.1957 | 0.0988 |
| PC | 9.2749 | 0.013 | 0.021 | 0.966 | 0.082 | 0.905 | 0.0883 | 0.0444 |
| $I_{BG}$ | 8.9724 | 0.003 | 0.167 | 0.829 | 0.040 | 0.956 | 0.0877 | 0.0440 |
| $CS_{BG}$ | 9.6586 | 0.014 | 0.029 | 0.957 | 0.162 | 0.824 | 0.0910 | 0.0458 |
| $LW_{BG}$ | 1.5675 | 0.000 | 0.081 | 0.919 | 0.440 | 0.559 | 0.0158 | 0.0079 |
| $LW_W$ | 2.3611 | 0.007 | 0.049 | 0.944 | 0.452 | 0.541 | 0.0239 | 0.0119 |
| $SP_P$ | 9.6952 | 0.015 | 0.002 | 0.983 | 0.240 | 0.745 | 0.0899 | 0.0453 |
| $TS_P$ | 8.5247 | 0.015 | 0.038 | 0.947 | 0.336 | 0.649 | 0.0779 | 0.0392 |
| $LS_P$ | 9.6952 | 0.014 | 0.008 | 0.978 | 0.214 | 0.772 | 0.0903 | 0.0454 |
| $TD_P$ | 9.3853 | 0.015 | 0.000 | 0.985 | 0.264 | 0.721 | 0.0862 | 0.0434 |

Table 6 (continued)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $PCC_P$ | 9.3853 | 0.010 | 0.158 | 0.832 | 0.139 | 0.851 | 0.0883 | 0.0444 |
| $PC_P$ | 9.3853 | 0.010 | 0.131 | 0.858 | 0.167 | 0.823 | 0.0881 | 0.0443 |
| $FP_W$ | 16.4583 | 0.010 | 0.191 | 0.799 | 0.004 | 0.987 | 0.1520 | 0.0755 |
| KL | 7.0721 | 0.006 | 0.064 | 0.930 | 0.003 | 0.991 | 0.0691 | 0.0344 |
| KH | 3.6332 | 0.000 | 0.004 | 0.996 | 0.001 | 0.999 | 0.0346 | 0.0173 |
| $FS_Y$ | 33262 | 0.0000 | 0.003 | 0.997 | 0.001 | 0.999 | 0.0326 | 0.0163 |
| $LW_Y$ | 0.8l.37 | 0.000 | 0.004 | 0.996 | 0.020 | 0.980 | 0.079 | 0.0040 |
| $LS_Y$ | 3.2365 | 0.000 | 0.001 | 0.999 | 0.008 | 0.991 | 0.0314 | 0.0157 |
| $TS_Y$ | 3.4007 | 0.000 | 0.000 | 1.000 | 0.008 | 0.992 | 0.0330 | 0.0165 |
| $TS_O$ | 8.4573 | 0.000 | 0.003 | 0.997 | 0.136 | 0.864 | 0.0853 | 0.0427 |
| $TD_Y$ | 3.4253 | 0.000 | 0.000 | 1.000 | 0.004 | 0.996 | 0.0331 | 0.0166 |
| $TC_Y$ | 3.5093 | 0.000 | 0.000 | 1.000 | 0.005 | 0.995 | 0.0344 | 0.0172 |
| $TC_O$ | 8.9516 | 0.000 | 0.035 | 0.965 | 0.034 | 0.966 | 0.0891 | 0.0446 |
| $PC_Y$ | 3.5093 | 0.000 | 0.001 | 0.999 | 0.005 | 0.995 | 0.0345 | 0.0172 |
| $PC_O$ | 8.9516 | 0.000 | 0.033 | 0.967 | 0.016 | 0.984 | 0.0887 | 0.0444 |
| $PC_K$ | 3.4439 | 0.000 | 0.001 | 0.999 | 0.005 | 0.995 | 0.0337 | 0.0168 |
| $R_B$ | 73567 | 0.008 | 0.078 | 0.914 | 0.014 | 0.978 | 0.0698 | 0.0348 |
| $R_P$ | 8.8015 | 0.000 | 0.079 | 0.921 | 0.002 | 0.998 | 0.0858 | 0.0429 |
| $R_K$ | 8.2535 | 0.003 | 0.001 | 0.996 | 0.074 | 0.923 | 0.0822 | 0.0411 |
| $S_P$ | 4.7551 | 0.037 | 0.005 | 0.958 | 0.233 | 0.730 | 0.0514 | 0.0258 |
| $S_B$ | 2.3953 | 0.007 | 0.022 | 0.971 | 0.147 | 0.846 | 0.0235 | 0.0118 |
| $S_K$ | 7.5631 | 0.012 | 0.050 | 0.938 | 0.236 | 0.753 | 0.0810 | 0.0404 |
| $S_T$ | 10.4160 | 0.000 | 0.038 | 0.962 | 0.001 | 0.999 | 0.1040 | 0.0520 |
| $R_T$ | 10.4160 | 0.001 | 0.535 | 0.465 | 0.277 | 0.723 | 0.1033 | 0.0514 |
| $NM_P$ | 8.7018 | 0.007 | 0.029 | 0.964 | 0.037 | 0.957 | 0.0897 | 0.0450 |
| $NM_B$ | 5.6694 | 0.000 | 0.030 | 0.970 | 0.005 | 0.995 | 0.0567 | 0.0284 |
| $FP_S$ | 14.7480 | 0.055 | 0.394 | 0.551 | 0.170 | 0.775 | 0.1397 | 0.0683 |
| $NM_K$ | 9.4897 | 0.011 | 0.000 | 0.989 | 0.124 | 0.865 | 0.0918 | 0.0458 |
| $FP_{BG}$ | 13.0517 | 0.007 | 0.157 | 0.837 | 0.003 | 0.991 | 0.1256 | 0.0625 |
| $FP_K$ | 11.0492 | 0.012 | 0.048 | 0.940 | 0.074 | 0.913 | 0.1100 | 0.0548 |

Table 7. Dynamic multipliers from 10 percent increase in corn price

| Period | $TS_B$ | $PC_B$ | $R_B$ | $FP_S$ | $TS_P$ | $PC_P$ | $R_P$ |
|---|---|---|---|---|---|---|---|
| 0 | -0.966% | -0.916% | 0.733% | 1.229% | -0.318% | -0.364% | 0.487% |
| 1 | -1.372% | -1.301% | 1.124% | 1.816% | -1.086% | -1.246% | 1.232% |
| 2 | -1.326% | -1.258% | 1.137% | 1.797% | -1.441% | -1.654% | 1.524% |
| 3 | -1.081% | -1.025% | 0.975% | 1.503% | -1.564% | -1.796% | 1.572% |
| 4 | -0.744% | -0.706% | 0.738% | 1.089% | -1.609% | -1.847% | 1.532% |
| 5 | -0.509% | -0.483% | 0.572% | 0.800% | -1.632% | -1.874% | 1.496% |
| 6 | -0.472% | -0.448% | 0.548% | 0.757% | -1.646% | -1.889% | 1.499% |
| 7 | -0.617% | -0.584% | 0.652% | 0.936% | -1.651% | -1.894% | 1.537% |
| 8 | -0.842% | -0.798% | 0.813% | 1.216% | -1.646% | -1.889% | 1.587% |
| 9 | -1.033% | -0.979% | 0.950% | 1.452% | -1.637% | -1.878% | 1.624% |
| 10 | -1.117% | -1.059% | 1.009% | 1.555% | -1.627% | -1.867% | 1.635% |
| 11 | -1.087% | -1.031% | 0.987% | 1.517% | -1.622% | -1.861% | 1.624% |
| 12 | -0.989% | -0.938% | 0.916% | 1.395% | -1.621% | -1.861% | 1.600% |
| 13 | -0.886% | -0.841% | 0.843% | 1.268% | -1.625% | -1.865% | 1.579% |
| 14 | -0.829% | -0.787% | 0.802% | 1.197% | -1.630% | -1.871% | 1.570% |
| 15 | -0.835% | -0.792% | 0.806% | 1.205% | -1.633% | -1.874% | 1.574% |
| 16 | -0.887% | -0.841% | 0.844% | 1.270% | -1.633% | -1.875% | 1.587% |
| 17 | -0.953% | -0.903% | 0.891% | 1.351% | -1.632% | -1.873% | 1.601% |
| 18 | -0.999% | -0.948% | 0.925% | 1.409% | -1.629% | -1.870% | 1.609% |
| 19 | -1.012% | -0.959% | 0.933% | 1.424% | -1.626% | -1.867% | 1.610% |
| 20 | -0.992% | -0.941% | 0.919% | 1.400% | -1.625% | -1.865% | 1.604% |
| 21 | -0.959% | -0.909% | 0.895% | 1.358% | -1.626% | -1.866% | 1.597% |
| 22 | -0.929% | -0.881% | 0.874% | 1.321% | -1.627% | -1.868% | 1.591% |
| 23 | -0.917% | -0.869% | 0.865% | 1.306% | -1.629% | -1.869% | 1.590% |
| 24 | -0.923% | -0.875% | 0.869% | 1.314% | -1.629% | -1.870% | 1.592% |

Table 7 (continued)

| Period | $FP_{BG}$ | $TS_Y$ | $TS_O$ | $PC_K$ | $FP_K$ | $R_K$ | $R_T$ |
|---|---|---|---|---|---|---|---|
| 0 | 0.691% | 0.006% | -0.023% | 0.005% | 0.438% | 0.360% | 0.325% |
| 1 | 2.003% | 0.018% | -0.041% | 0.017% | 0.634% | 0.579% | 0.414% |
| 2 | 2.571% | 0.025% | -0.042% | 0.024% | 0.629% | 0.600% | 0.374% |
| 3 | 2.725% | 0.026% | -0.035% | 0.025% | 0.541% | 0.530% | 0.281% |
| 4 | 2.732% | 0.023% | -0.026% | 0.023% | 0.423% | 0.421% | 0.159% |
| 5 | 2.724% | 0.019% | -0.020% | 0.019% | 0.351% | 0.347% | 0.075% |
| 6 | 2.740% | 0.017% | -0.020% | 0.016% | 0.352% | 0.338% | 0.059% |
| 7 | 2.775% | 0.017% | -0.024% | 0.016% | 0.413% | 0.388% | 0.108% |
| 8 | 2.812% | 0.019% | -0.030% | 0.018% | 0.495% | 0.462% | 0.186% |
| 9 | 2.834% | 0.022% | -0.036% | 0.021% | 0.557% | 0.524% | 0.255% |
| 10 | 2.835% | 0.025% | -0.037% | 0.023% | 0.579% | 0.550% | 0.287% |
| 11 | 2.820% | 0.025% | -0.036% | 0.024% | 0.561% | 0.538% | 0.278% |
| 12 | 2.801% | 0.025% | -0.033% | 0.024% | 0.523% | 0.505% | 0.244% |
| 13 | 2.786% | 0.024% | -0.031% | 0.023% | 0.488% | 0.471% | 0.207% |
| 14 | 2.783% | 0.022% | -0.029% | 0.021% | 0.472% | 0.454% | 0.186% |
| 15 | 2.789% | 0.022% | -0.030% | 0.021% | 0.478% | 0.457% | 0.188% |
| 16 | 2.800% | 0.022% | -0.031% | 0.021% | 0.498% | 0.474% | 0.206% |
| 17 | 2.810% | 0.023% | -0.033% | 0.022% | 0.522% | 0.496% | 0.229% |
| 18 | 2.815% | 0.023% | -0.034% | 0.023% | 0.536% | 0.510% | 0.246% |
| 19 | 2.813% | 0.024% | -0.034% | 0.023% | 0.538% | 0.514% | 0.251% |
| 20 | 2.808% | 0.024% | -0.034% | 0.023% | 0.530% | 0.508% | 0.244% |
| 21 | 2.802% | 0.024% | -0.033% | 0.023% | 0.517% | 0.496% | 0.233% |
| 22 | 2.798% | 0.023% | -0.032% | 0.022% | 0.507% | 0.487% | 0.222% |
| 23 | 2.798% | 0.023% | -0.032% | 0.022% | 0.504% | 0.483% | 0.217% |
| 24 | 2.801% | 0.023% | -0.032% | 0.022% | 0.508% | 0.485% | 0.219% |

## Summary

This paper presents an econometric policy simulation model of the U.S. livestock sector. The primary benefit of the model is that it incorporates recent developments in the literature on price analysis and model specification into a sector level model. The model developed is useful for assessing policy and technology impacts and capturing the substitution and, hence, market share implications between the competing meat industries.

Future work will likely revolve around certain components of the model. For example, price response is not adequately captured by the output price-input cost ratio used in the estimation. Better response will likely be gained from the specification of explicit dynamic industry profit functions. Additional issues also remain with respect to demand estimation and margin specification.

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