A five-commodity econometric simulation model of the U.S. livestock and poultry sector

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A FIVE-COMMODITY ECONOMETRIC SIMULATION MODEL
OF THE U.S. LIVESTOCK AND POULTRY SECTOR

by
Roland K. Roberts

and
Earl O. Heady

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Center for Agricultural and Rural Development
Iowa State University
Ames, Iowa 50011

March 1979
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Production
Inventory
Consumption
Retail Price
Farm-retail Margin
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INTRODUCTION

The livestock and poultry sector of the U.S. agricultural economy is influenced to a large extent by government grain policies. However, in the past government policymakers concerned themselves mostly with certain commodities in the crop sector, putting little direct emphasis on the impact of recommended policies upon the livestock and poultry sector. Robinson [36, p. 770] summarizes the past treatment of the livestock and poultry sector as follows:

Policies adopted with respect to grains obviously do influence the prices of livestock products...These secondary effects will be considered, but the important point to keep in mind is that most policy discussions, now as in the past, focus on grains and tend to ignore the rest of agriculture. I plead guilty to following this well-established tradition.

Government grain policies of the early 1970s which returned U.S. agriculture to a free market situation are an example of the ignored condition of the livestock and poultry sector in policy formulation. An element of uncertainty not known for many years was reintroduced under the extreme fluctuations in grain prices in the free market. Feed prices began to increase as reserves of grains were depleted through high levels of exports. Not only were profit margins in livestock production reduced but also feed prices became highly volatile after many years of stabilizing government programs. The government no longer had vast grain stocks to cushion the effects of weather and other stochastic events.
Grain policies which cause the livestock and poultry sector to serve as a buffer to cushion the effects of grain shortfalls and surpluses caused by weather and/or changing export demands not only ignore this important sector but also can be detrimental to it. In providing a buffer service the livestock and poultry sector is subjected to fluctuating feed prices which ration the existing supply of grains by encouraging large increases or decreases in the number of animals fed on farms.

Until recent times, farmers in general were more diversified and a large proportion had both grain and livestock enterprises. Uncertainties associated with large fluctuations in grain prices were mitigated by adjusting the number of animals fed on farms. In years of high grain prices farmers would decrease their livestock enterprises while low grain prices would encourage farmers to feed more of their grain to livestock giving them incentive to expand their livestock enterprises. If grain prices increased and livestock enterprises were reduced, the two changes tended to offset each other in their impact on income. Lower grain prices and larger, more profitable livestock enterprises had similar offsetting results on income. In recent years, however, the livestock and poultry industries have undergone major structural change. Government grain policies and farm mechanization have encouraged specialization in livestock and poultry production. In periods when uncertainties caused by fluctuating feed prices were eliminated to a great extent by government price support programs, highly specialized feedlots and hog farms resulted. The broiler and
turkey industries expanded and became more efficient as specialization occurred. But, the specialization caused livestock and poultry farmers to be increasingly vulnerable to the uncertainties and fluctuating prices. This increased vulnerability has not been given sufficient consideration in farm price and income policies. Breimyer and Rhodes (4, p. 945) suggest that in recent years livestock and poultry have received less consideration than in the past;

...historically, livestock and poultry got more attention when they were still closely connected with feed production on the farm. In the early years of farm programs, the 'ever-normal granary' was consciously designed to level out the supply and price of feed for livestock and poultry. Now that livestock and poultry have become more commercial and more vulnerable to a volatile feed situation, feed price stabilization has been progressively removed from the councils of farm policy.

Government grain policies of the 1950s and 1960s were highly beneficial to producers of livestock and poultry products because they encouraged stable and more certain feed prices. Perhaps livestock and poultry industries received too little consideration as the free market grain policies of the 1970s were being implemented. The highly volatile prices and supplies of livestock and poultry products in the 1970s with their accompanying impacts on farm income and food prices, provide a basis for considering the livestock and poultry sector equally with grain as future agricultural policies are formulated.

OBJECTIVES

Simulation models of U.S. agriculture frequently have been used to evaluate the impacts of various government policies upon the grain
sector. The purpose of this study is to develop a five-commodity livestock and poultry model which can be linked to national crop simulation models. This livestock and poultry model presented not only can be used to evaluate the impact of grain policies upon the livestock and poultry sector but also can be used to evaluate the impact of other government policies, such as import quotas, on the five livestock and poultry commodities.

Crop simulation models can be linked to the livestock and poultry model through five equations (one for each commodity) which estimate production as a function of a weighted average of feed grain and soybean prices as well as other relevant variables. Influences of the livestock and poultry sector upon the crop sector can be captured by introducing into the crop feed demand equations a weighted average livestock and poultry price. Also, livestock and poultry production in millions of pounds of meat can be converted to livestock production units and included in the crop feed demand equations. Work is being done to link the model presented in this paper with a revised and updated version of the simulation model used at the Center for Agricultural and Rural Development [34, 35].

MODEL STRUCTURE

The model includes beef, pork, lamb, chicken and turkey subsectors. Each subsector contains seven equations. These equations explain

1Further details are given in a later section which deals with the production equations.
current production, inventories (end-of-year commodity stocks), civilian consumption, retail prices, farm-retail margins, gross farm values (farm values for chicken and turkey), and cash receipts. The production, inventory, retail price, farm-retail margin, and cash receipts equations are estimated econometrically while the civilian consumption and gross farm value variables are determined by behavioral identities which complete the model structure.  

The 35 equations are structured into a block recursive framework. A block recursive model is composed of equations which can be classified into groups. The equations within any group are determined simultaneously while equations across groups are determined recursively. A system of equations or groups of equations is recursive if the equations or groups of equations can be determined sequentially [32, p. 270].

The production, inventory, civilian consumption, and retail price equations form a recursive system. Production is determined first based upon exogenous variables and lagged prices. The inventory equation is then determined with current production as an explanatory variable. Both current production and current inventory help determine civilian consumption. Once civilian consumption is determined it is used as an explanatory variable in the retail price equation.

2 Gross farm value is used in conjunction with beef, pork, and lamb, while farm value is used in conjunction with chicken and turkey. These are prices received by farmers for a quantity of live animal or bird equivalent to one pound or meat sold at the retail level. The word "gross" refers to the inclusion of the value of offals and other byproducts.
The farm-retail margin and the gross farm value equations form a simultaneous block. The farm-retail margin equation contains current gross farm value and the gross farm value identity contains current farm retail margin. This simultaneous block is recursive with the retail price equation and the cash receipts equation. Cash receipts can be determined only after the simultaneous equations have been solved which, in turn, can be solved only after the retail price equation has been solved. Hence, the model is block recursive. A detailed explanation of the model equations and linkages is presented later.

STATISTICAL CONSIDERATIONS

The Data

Time series data are used to estimate the structural equations of the model. Data were gathered for a 24-year period from 1953 through 1976 for most variables. Shorter sample periods were used for some variables because of insufficient data. The lamb gross farm value and farm-retail margin series include 23 years from 1953 through 1975. Turkey farm value and farm-retail margin cover the period from 1956 through 1975. Variable definitions and a list of data sources are given in later sections.

Recursive Equations

Ordinary least squares is the statistical estimation technique applied to the recursive equations of the model. For ordinary least squares to be appropriate the error terms among the recursive equations
must be uncorrelated. An assumption of uncorrelated errors among equations frequently is appropriate for a recursive system of equations because no right-hand side current endogenous variable need be correlated with the error term. Each endogenous variable in a recursive system is necessarily correlated only with the error term of the equation which determines it. Therefore, when an endogenous variable which has been determined in a previous equation is included on the right-hand-side of an equation it is not necessarily correlated with the error term of that equation [43, pp. 460-61]. However, recursiveness does not guarantee uncorrelated errors. If the errors are correlated among the equations, then right-hand-side current endogenous variables are correlated with the error terms of the equations in which they appear and a simultaneous estimation technique such as three-stage least squares would be more appropriate [32, pp. 269, 282].

The assumption of uncorrelated errors implicit in the use of ordinary least squares was made only after certain tests were performed. In this case a test was performed on each equation which contained a current endogenous variable on the right-hand-side. The test consisted of reestimating an equation with an additional variable. The new variable was the estimated residual from the equation which previously determined the right-hand-side endogenous variable. A two-tailed t-test was performed on the coefficient of the estimated residual. A significance level of 5 percent was chosen prior to the test. In no case was the estimated residual significant at the 5 percent level. A significant estimated residual would have indicated that the error terms
among the equations were correlated. It was concluded that the assumption of uncorrelated error terms was appropriate. Hence, ordinary least squares was used, in most instances, as the estimation technique for the production, inventory, retail price, and cash receipts equations.  

Test for Autocorrelation

Another assumption necessary for ordinary least squares estimation is that the errors terms within an equation from observation to observation are independent. The ordinary least squares estimators are not efficient if the error terms are correlated and therefore are not the best linear unbiased estimators.

The Durbin-Watson statistic frequently is used to test for autocorrelation. If the Durbin-Watson statistic indicates significant autocorrelation then some form of autoregressive estimation technique can be used to obtain efficient estimators. Many of the equations in this livestock and poultry model contain lagged dependent variables as independent variables. The Durbin-Watson statistic thus is rendered inappropriate because it is biased toward indicating no autocorrelation [43,p. 414].

An autoregressive least squares regression technique available from Martin's Computer Algorithm [33, p. 5-7] was used to test each equation in the livestock and poultry model for autocorrelation. The estimated autoregressive parameter \( \hat{\beta} \) was tested for significance at the

Refer to Appendix D for a detailed explanation of the above test.
When significance at the 5 percent level was found, the equation estimated by autoregressive least squares was used in the model. If no significance was found, the equation estimated by ordinary least squares was used. Only in the case of the cash receipts equations for beef, pork, lamb, and chicken was found to be significant. Autoregressive least squares equations were used for these equations.

Simultaneous Equations

The estimation technique applied to the simultaneous equations of the model is two-stage least squares. The farm-retail margin equation in each subsector is the only equation estimated with this method. Two-stage least squares is appropriate because current gross farm value is included on the right-hand-side of the farm-retail price equation. The gross farm value is correlated with the error term making ordinary least squares inappropriate [32, pp. 267-68].

Reduced form equations are derived from the estimated farm-retail margin equation and the gross farm value identity. Reduced form equations express the two endogenous variables in terms of the exogenous and predetermined variables. Expressed in this form, values for farm-retail margin and gross farm value can be solved directly without any iterative computer techniques.
Tests of Significance

The significance of the coefficients throughout this paper is evaluated based upon t-statistics. A one-tailed test is used for all coefficients for which economic theory dictates a specific sign. A one-tailed test is acceptable because theoretically incorrect signs are not accepted regardless of the size of the t-statistic. A two-tailed test is used for those coefficients for which economic theory dictates no specific sign.

MODEL EQUATIONS

A more detailed examination of the model equations is presented in this section. The equations are presented in the same sequential order in which they occur in the computer simulation model.

Production

The production equations are presented in this section. A list of variables and definitions used in these equations is presented first, followed by the derivation of a general theoretical production equation. The empirical results for each subsector are then presented.

Variable definitions

The following time series variables are used to estimate the production equations:

---

4 Refer to Appendix B for the sources of the data used in the estimation of the model equations.
i-PROD = production in millions of pounds of carcass or ready-to-cook weight meat for the ith commodity where i = B(beef), P(pork), L(lamb and mutton), C(chicken), and T(turkey).\(^5\)

i-FP = gross farm value for beef (choice), pork and lamb (choice), and farm value for chicken and turkey deflated by the index of prices paid by farmers with 1967 = 100.\(^6\) Gross farm value and farm value are prices paid to farmers for a quantity of live animal or bird equivalent to one pound of retail cuts or ready-to-cook bird.

i-FC = a weighted average feed grain and soybean price per hundred pounds of feed for the ith commodity (i=B,P,L,C, and T) deflated by the index of prices paid by farmers with 1967 = 100. These variables are taken as proxies for feed costs.\(^7\)

(\(\text{MA2}\)) = a two-year equally-weighted moving average of the accompanying variable.

(\(\text{MA3}\)) = a three-year equally-weighted moving average of the accompanying variable.

\(^5\)Throughout this report quantities of beef, pork and lamb and mutton are in carcass weight, while quantities of chicken and turkey are in ready-to-cook weight.

\(^6\)The index of prices paid by farmers is used as a deflation factor in the production equations to represent the decline in the purchasing power of farm income.

\(^7\)Refer to Appendix A for further explanation of the derivation of the feed cost variables.
RFC = an index of range feed conditions in 17 western states. RFC ranges from 49 or below indicating very bad to 100 and over indicating excellent range feed conditions.

PFDUM = a dummy variable with 1973=1 and 0 otherwise to account for the effect of the price freeze in 1973.


LNT = the natural log of T.


T-INV = end-of-year stocks of turkey in millions of pounds of ready to cook bird.

t = the current year.

**General equation structure**

The theoretical model assumed for the production equations is similar to that suggested by Nerlove [30]. It is assumed that farmers have static expectations and that they base current production plans upon past prices. Hence, the long-run supply equation can be written as,

\[
i\text{-EPROD}_t = a_0 + a_1 \text{i\text{-FP}}_{t-1} + a_2 \text{i\text{-FC}}_{t-1} + a_3 \text{PFDUM} + a_4 T + U_t, \tag{1}
\]

where \(i\text{-EPROD}\) is the long-run equilibrium level of meat production of the \(i\)th commodity, the \(a\)'s are parameters, \(U\) is a disturbance term, and all other variables are as defined in the previous subsection.
The time trend is not assumed to be a proxy for technological change alone. It represents variations in meat production due to variables not included explicitly in the equation but which have caused production to increase or decrease over time.

The relationships between actual and long-run equilibrium production is assumed to be,

$$i-\text{PROD}_t - i-\text{PROD}_{t-1} = \lambda [i-\text{EPROD}_t - i-\text{PROD}_{t-1}],$$

where $\lambda$ (the coefficient of adjustment) is the portion of the gap between current long-run equilibrium production and the previous year's actual production which is closed in one year. Neither equation 1 nor equation 2 can be estimated directly because $i-\text{EPROD}_t$ is unobservable. Substituting equation 1 into equation 2 and solving for $i-\text{PROD}_t$ results in the following equation which can be estimated,

$$i-\text{PROD}_t = a_o \lambda + a_1 \lambda \cdot i-\text{FP}_{t-1} + a_2 \lambda \cdot i-\text{FC}_{t-1} + a_3 \lambda \cdot \text{PFDUM} + a_4 \lambda T$$

$$+ (1-\lambda) \cdot i-\text{PROD}_{t-1} + U_t,$$

where all symbols are as defined earlier.

Variations of the production equation proposed above are estimated for each of the five commodity subsectors. Moving averages of $i-\text{FP}$ and $i-\text{FC}$ are used in many cases. The biological and cyclical nature of the various livestock and poultry industries encourages farmers to use their price experiences for several past periods directly in determining production plans.
The theory of the firm suggests that the sign of $a_1$ should be positive while the sign of $a_2$ should be negative. The coefficient for PFDUM is expected to be negative and the coefficient for $i$-PROD$^{t-1}$ to be positive, while the coefficient for time could have either sign.

The final results of the production equations are presented in the following sections. Each estimated equation is presented along with $t$-statistics in parentheses below the coefficients. The coefficient of determination ($R^2$), mean square error (MSE), and the Durbin-Watson statistic (DW) also are given.

To conserve space and to avoid repetition, the analysis of the coefficients is presented without making reference to the ceteris paribus assumption unless otherwise indicated.

**Beef production**

$$B-PROD_t = 13317.0781 + 54.7070 \times B-\text{FP(MA3)}_{t-1} / B-\text{FC(MA3)}_{t-2} (1.730)$$

$$- 172.8341 \times RFC_t - 2633.0070 \times TIN (5.268) (1.848)$$

$$- 1261.2200 \times \text{PFDUM} + .9755 \times B-\text{PROD}^{t-1} (2.543) (24.844)$$

$$(4)$$

$$R^2 = .9909, \text{ MSE} = 185850.3934, \text{ DW} = 1.8202.$$
percent level. Other specifications of these price variables led to nonsignificance or incorrect signs. The specification presented here provided the most satisfactory statistical results and improved the simulation results.

The range feed condition index explains some of the variability in beef production due to weather. The negative sign is consistent with economic theory. As range feed conditions deteriorate the index of range feed conditions decreases. Range feed becomes a more scarce commodity. Farmers react by reducing their herd sizes. Larger proportions of young animals are sold for slaughter causing beef production in pounds of meat to increase. Hence, a negative relationship prevails. A decrease (increase) in $\text{RFC}_t$ by one point causes beef production to increase (decrease) by 17 million pounds. The coefficient is significant at the 1 percent level.

The inverse of time is the time variable used. It indicates that beef production increases at a decreasing rate over time. Again, time inverse is not a proxy for technological change but including it in the equation provides more accurate estimates of the other coefficients in the sense that more of the total variability in beef production is explained. The coefficient is significant at the 10 percent level.

A price freeze was placed on beef from March 29 to September 10, 1973, by executive order [19, p. 7]. As a result, farmers reduced the sales of their cattle for slaughter in anticipation of increased prices when the price freeze ended. Thus, beef production declined in that
year. As can be seen, the price freeze caused a decrease in beef production of 1261.22 million pounds in 1973. This variable is significant at the 5 percent level.

The coefficient for lagged beef production is highly significant and has a value of .98. The estimated coefficient of adjustment is .02. The low level of λ indicates that the beef subsector is slow to adjust to changes in prices or other influences which move it away from long-run equilibrium production.

The independent variables explain virtually all of the variation in beef production as indicated by the $R^2$ of .9909.

Pork production

\[
P_{PROD_t} = 2554.6797 + 97.0674 P_{FP_{t-1}} - 1390.6426 P_{FC_{t-1}} + 1690.7600 P_{FDUM} + .8025 P_{PROD_{t-1}}
\]

(3.989) \hspace{1cm} (4.070) \hspace{1cm} (2.376) \hspace{1cm} (5.853)

\[R^2 = .7815, \ MSE = 390885.2745, \ DW = 2.0737.\]

The coefficient for $P_{FP_{t-1}}$ is significant at the 1 percent level. The positive sign is theoretically correct and the coefficient predicts that pork production increases by 97.1 million pounds if $P_{FP_{t-1}}$ increases by 1 cent per pound.

$P_{FC_{t-1}}$ also has a coefficient which is significant at the 1 percent level and its sign is theoretically correct. A decrease in

\[8\text{The estimated coefficient of adjustment is obtained by subtracting the estimated coefficient for the lagged dependent variable from 1.}\]
pork production by 1390.6 million pounds is associated with an increase in $P_{FC_{t-1}}$ by one dollar per hundred pounds.

A price freeze was placed on pork from March 29 through August, 1973 [19, p. 7]. The PFDUM variable indicates that pork production was reduced by 1690.8 million pounds in 1973 from what it would have been without the price freeze. Based on a one-tailed test, the coefficient is significant at the 5 percent level.

The coefficient for lagged pork production yields an estimated coefficient of adjustment of .20. The size of the estimated $\lambda$ suggests that the pork subsector adjusts more rapidly to long-run equilibrium production than does the beef subsector. This result is expected because of the shorter life cycle for hogs and because hogs are bred year round. The coefficient for $P_{PROD_{t-1}}$ is significant at the 1 percent level.

The $R^2$ indicates that 78.15 percent of the variability in pork production is explained by the independent variables. This is lower than for any of the other subsector production equations. Nevertheless, an $R^2$ of .7815 can be accepted when considered along with the significance of the coefficients of the independent variables. Although there are other influences not accounted for, the reliability of the variables included is high.
Lamb production

\[
L-PROD_t = \frac{56.0480 + 95.9382*L-FP(MA3)_{t-1}}{(2.284)} / L-FC(MA3)_{t-1} - 6.4792*T + .8401*L-PROD_{t-1} \\
(3.251) (8.310)
\]

\[R^2 = .9572, \ MSE = 808.7077, \ DW = 1.3252.\]

The ratio of \(L-FP(MA3)_{t-1}\) to \(L-FC(MA3)_{t-1}\) has an estimated coefficient of 95.9. It is significant at the 5 percent level. Both time and lagged production are significant at the 1 percent level.

The estimated coefficient of adjustment for lamb and mutton production of .16 is higher than for beef but lower than for pork. This result is expected because the life cycle for sheep is longer than for hogs and shorter than for beef animals.

Practically all of the variability in lamb and mutton production (95.72 percent) is explained by the independent variables. The Durbin-Watson statistic is within the inconclusive region at the 5 percent level of significance. However, as indicated in an earlier section, further analysis revealed no significant autocorrelation.

Chicken production

\[
C-PROD_t = 2546.2349 + 40.8683*C-FP_{t-1} - 482.6930*C-FC_t \\
(3.721) (6.052)
+ 255.1748*T + .2333*C-PROD_{t-1} \\
(6.932) (1.618)
\]

\[R^2 = .9950, \ MSE = 21318.9312, \ DW = 1.8543.\]
The coefficient for lagged farm value of chicken is significant at the 1 percent level. A unit change in farm value brings about a change in the same direction of 40.9 million pounds of ready-to-cook chicken produced.

The variable $C-FC_t$ is used because of its one quarter lag from current chicken production. The one quarter lag exists because season average feed grain and soybean prices with seasons starting October 1 and September 1, respectively, are used to form feed cost variables. The one quarter lag in feed costs is advantageous in the chicken production equation because only seven to eight weeks are required to produce a 3.5 pound broiler [3, p 7]. The broiler industry is able to respond rapidly to changes in prices because of the short production cycle of chickens as compared to cattle, hogs and sheep.

A simultaneous approach was at first considered but statistical estimates yielded both theoretically incorrect signs for the current farm value and cost variables and nonsignificant coefficients. Results for $C-FC_{t-1}$ also were unsatisfactory possible because the lag of 15 months was too long. Equation 7 was considered to represent both the practical and theoretical aspects of chicken production better than other specifications tried.

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9 Refer to Appendix A for further explanation of the derivation of the feed cost variables.
The coefficient for \( C-FC_t \) is significant at the 1 percent level and indicated that chicken production decreases by 482.7 million pounds when \( C-FC_t \) increases by one dollar per hundred pounds.

Chicken production is predicted to increase by 255.2 million pounds per year over the 1953-76 period. Costs of production have declined over time due to improved breeds, production techniques, and other technological advances. Because of these advances, production time required to obtain market weight has declines from 12 to 14 weeks in the early 1950s to from 7 to 8 weeks at the present [3, p. 7]. These and other influences cause the coefficient for \( T \) to be significant at the 1 percent level.

Based on a one-tailed test, lagged chicken production is significant at the 10 percent level. The estimated coefficient of adjustment is .77 which, as expected, is much larger than for beef, pork or lamb. Chicken production adjusts rapidly to equilibrium with 77 percent of the gap between lagged actual and long-run equilibrium production being filled within one year.

The independent variables explain 99.50 percent of the variance in chicken production.

Turkey production

\[
T-PROD_t = -738.1287 + 37.8253*FP_{t-1} / T-FC(MA2)_t \\
- 1.0016*INV_{t-1} + 440.4804*LNT + .6541*T-PROD_{t-1}^{'} \quad (8)
\]

\[ R^2 = .9329, \quad MSE = 7159.9737, \quad DW = 2.3180. \]
The ratio of the farm value lagged one year to the two-year weighted average feed cost is significant at the 5 percent level. The price and cost variables in this ratio form prove to be more significant and provide a lower mean square error estimate for turkey production than do these same variables when entered into the equation separately. The ratio is also formed to conserve degrees of freedom because the equation is being estimated with only 19 observations.

The two-year equally-weighted moving average of feed costs gives better statistical results than do either current feed costs or lagged feed costs. Three to five more months are required to produce a turkey to market weight, as compared to a broiler [37, p. 7]. The feed cost variable expressed in the above manner takes into account the longer production period required for turkeys.

Turkey consumption is seasonal in nature. Consequently, the quantity of turkey in cold storage increases in the early fall in preparation for the holidays. Liquidation of cold storage begins with the holiday season and continues into the summer. Soliman [37, p. 7] hypothesized in his quarterly model that producers make plans for future production based upon the quantity of turkey in cold storage. The variable $T-INV_{t-1}$ is included in equation 8 to account for this possible phenomenon. It is hypothesized that when inventories in cold storage on December 31 are high, producers plan to produce less during the next year. The coefficient with a negative sign, significant at the 5 percent level, seems to confirm this hypothesis.
The coefficients for LNT and $T_{PROD}^{t-1}$ are both significant at the 5 percent level. The coefficient of adjustment, .35, is smaller than for chicken but larger than for beef, pork, and lamb and mutton production. The independent variables explain 93.29 percent of the variance in turkey production.

Inventory

The inventory equations for the five livestock and poultry subsectors are presented for each of the five submodel commodities.

Variable definitions

The variables defined below are used in the inventory equations:

$i-INV = \text{end-of-year stocks of the } i\text{th commodity in millions of pounds of carcass weight for beef, pork, and lamb and mutton and ready-to-cook weight for chicken and turkey.}$

$i-PROD = \text{production in millions of pounds of carcass or ready-to-cook weight meat for the } i\text{th commodity (i=B,P,L,C, and T).}$

$PLCT-PROD = \text{the sum of the production of pork, lamb and mutton, chicken, and turkey in millions of pounds.}$

$BLCT-PROD = \text{the sum of the production of beef, lamb and mutton, chicken, and turkey in millions of pounds.}$

$BPCT-PROD = \text{the sum of the production of beef, pork, chicken, and turkey in millions of pounds.}$

$PFDUM = \text{a dummy variable with } 1973=1 \text{ and 0 otherwise to account for the effects of the } 1973 \text{ price freeze.}$

LNT = the natural log of T.

t = the current year.

General equation structure

The end-of-year stock of meat is equal to the quantity supplied (beginning stock plus production plus imports) throughout the year minus the quantity consumed domestically and exported. An increase in production, other things held constant, increases supply and hence end-of-year stocks also increase. Therefore, a positive relationship between current production and end-of-year stocks is expected to prevail.

A great deal of competition exists among the five submodel commodities. An increase in the production of one competing meat, other things held constant, causes prices of other competing meats to decline. Based upon economic theory, a change in relative prices should cause substitution among competing commodities in consumption. In this case a decline in the relative prices of other meats would cause their consumption to increase and bring about a decrease in consumption of the meat in question causing inventories to increase, other things constant. Therefore, a positive relationship is hypothesized between the production of other meat and the end-of-year stock for a particular meat.

Meat packers vary their inventories in anticipation of increased or decreased prices. The 1973 price freeze kept prices from increasing along the inflationary trend which prevailed at that time. Meat packers
anticipated large price increases when the price freeze was lifted. As a consequence they accumulated larger-than-normal inventories, expecting to sell them at higher prices later. A dummy variable reflecting the price freeze is considered in the inventory equation. It is expected that the price freeze caused ending inventories to increase.

Meat packers try to hold an equilibrium level of inventories for transactions and speculative purposes. They constantly try to reach and maintain that level of equilibrium. For this reason lagged inventory is included as an explanatory variable. A negative sign indicates that meat packers over adjust to equilibrium. If last year's inventory was low in relation to equilibrium, a negative sign indicates that this year's inventory will be high in relation to equilibrium. A positive sign indicates only a partial adjustment to equilibrium.

The proposed model for the inventory equation is:

\[ i-INV_t = a_0 + a_1*i-INV_{t-1} + a_2*SUM-PROD_t + a_3*PFDM + a_4*T + a_5*i-INV_{t-1} + U_t \]  

(9)

where SUM-PROD is the sum of the production of meats other than for commodity i in millions of pounds of carcass and ready-to-cook weight, U is a disturbance term and all other variables are as defined earlier.

Several variations of equation 9 were estimated for each submodel. Based upon several criteria, the final equations presented below were selected. The performance of the equation in the simulation model, the significance of the coefficients, the sign of the coefficients, and the
size of the mean square error relative to those of other equations were several of the criteria considered.

The inventory equations and related statistics are given in the following sections. The coefficients are analyzed without repeated reference to the fact that other variables are held constant.

**Beef inventory**

\[
B\text{-INV}_t = 277.9915 + 0.0252B\text{-PROD}_t + 0.0177PLCT\text{-PROD}_t - 86.9550LNT_t + 126.2508PFDUM_t - 0.2574B\text{-INV}_{t-1},
\]

\[
(4.561) \quad (2.694) \quad (1.616)
\]

\[R^2 = 0.9266, \quad MSE = 802.3171, \quad DW = 1.8171.\]

Current beef production has the expected positive coefficient. The coefficient is significant at the 1 percent level and suggests that an increase in beef production by one million pounds is accompanied by an increase in beef inventory by 25,200 pounds.

An increase in PLCT\text{-PROD}_t by one million pounds brings about an increase in beef inventory by 17,700 pounds. The coefficient is also significant at the 1 percent level.

The coefficients for LNT and PFDUM are both significant at the 1 percent level. The 1973 price freeze caused an increase in beef inventory by 126 million pounds as indicated by the coefficient of PFDUM. The negative coefficient for LNT suggests a decreasing trend in beef inventory.
Although the coefficient for lagged inventory is nonsignificant, \( B\text{-INV}_{t-1} \) is retained because of increased accuracy of the simulation results, an increased \( R^2 \), and a reduced mean square error. The negative coefficient suggests that meat packers over adjust to the equilibrium level of inventory. However, the nonsignificance of the coefficient might cause some to discount the implications of the negative sign.

The equation explains 92.66 percent of the yearly variation in beef inventory.

\[
P\text{-INV}_t = -161.2783 + 0.0506*\text{P-PROD}_t + 0.0191*\text{BLCT-PROD}_t + 276.9488*\text{LNT}_t - 64.0776*\text{PFDUM} - 0.2028*\text{P-INV}_{t-1} \tag{11}
\]

\( R^2 = 0.7056 \), \( MSE = 2008.6004 \), \( DW = 1.8127 \).

The coefficients for pork production, the sum of the production of other meats, and the log time trend are all significant at the 1 percent level. An increase in pork production of one million pounds brings about an increase in inventory by 50,600 pounds while an increase of one million pounds in the production of other meats causes pork inventory to increase by 19,100 pounds. The negative coefficient for \( \text{LNT} \) indicates a decreasing trend in inventory over time.

The price freeze dummy variable is significant at the 10 percent level, and the coefficient indicates that the price freeze led to an increase in inventory by 64.1 million pounds.
The coefficient for lagged inventory is nonsignificant at the 10 percent level. However, lagged inventory is left in the equation because of improved simulation results and because the $R^2$ and mean square error are substantially improved.

The $R^2$ indicates that 70.56 percent of the variance in pork inventory is explained by the independent variables. The $R^2$ for the pork inventory equation is lower than for any of the other inventory equations.

**Lamb inventory**

\[
L-INV_t = -60.7161 + 0.0498*L-PROD_t + 0.0015*BPCT-PROD_t - 3.2665*LNT - 0.5172*L-INV_{t-1} \\
(5.463) 
(4.762) 
(1.751) 
(2.672) \\
R^2 = 0.7724, 
MSE = 3.1482, 
DW = 2.0581.
\]

Coefficients for both current lamb and mutton production and the sum of the production of other meats are significant at the 1 percent level. These coefficients are both positive, suggesting that lamb and mutton inventory increases with increased lamb and mutton production or increased production of other meats.

The coefficient for LNT is significant at the 10 percent level and the coefficient for lagged inventory is significant at the 5 percent level. The negative coefficient for lagged inventory suggests that meat packers overadjust to the equilibrium level of inventory.
The price freeze dummy variable was deleted from the final equation because of an incorrect sign and nonsignificant coefficient.

The equation is generally acceptable. The coefficients retained are all significant at acceptable levels. The $R^2$ is higher than for the pork equation, but lower than for the beef and turkey equations.

**Chicken inventory**

Chicken end-of-year inventory is assumed to be exogenous. The variation in chicken inventory seems to be random. Many specifications of the hypothesized inventory equation were estimated. None of the variables were found to be significant. The highest $R^2$ obtained was .1713, which indicates that only 17.13 percent of the variation was explained.

**Turkey inventory**

$$T-\text{INV}_t = -209.5561 + .3732*T-\text{PROD}_t - 18.4195*T_t \quad (7.376) \quad (6.300)$$

$$+ 49.3820*\text{PF Dum} + .5125*T-\text{INV}_{t-1} \quad (1.824) \quad (4.648)$$

$$R^2 = .8696, \quad \text{MSE} = 619.4089, \quad \text{DW} = 2.2782.$$ (13)

The coefficient for $T-\text{PROD}_t$ which is significant at the 1 percent level, is large relative to the coefficient for current production in the other inventory equations. An increase in current turkey production by one million pounds brings about an increase in turkey inventory by 373,200 pounds. This result is expected because of the seasonal nature of turkey
consumption. The ratio of turkey inventory to turkey production is greater than the same ratio for any of the other commodities. The inventory-production ratio for turkey averages .143 over the sample period and for beef, pork, and lamb, respectively, it averages .015, .022, and .022. A larger portion of turkey production goes into cold storage, hence, a larger coefficient for current production results.

The sum of the production of other meats was estimated with a nonsignificant negative coefficient and was therefore deleted from the final equation.

Lagged inventory, as opposed to the same variable in the other inventory equations, has a positive coefficient indicating partial adjustment to equilibrium. The coefficient is significant at the 1 percent level.

The independent variables explain 86.96 percent of the variance in turkey inventory.

Civilian Consumption

The civilian consumption behavioral identities are presented on the following pages. Included variables are defined followed by an explanation of the general structure of the civilian consumption identity. The five submodel commodity identities are then presented.

Variable definitions

The variables defined below are used in the civilian consumption behavioral identities:
i-CONS = civilian consumption in millions of pounds of carcass weight or ready-to-cook weight meat for the ith commodity where i=B(beef), P(pork), L(lamb and mutton), C(chicken), and T(turkey).

i-PROD = production in millions of pounds of carcass weight or ready-to-cook weight meat for the ith commodity where i=B,P,L,C, and T.

i-IMP = imports in millions of pounds of carcass weight meat for i=B,P, and L.

i-EXP = exports in millions of pounds of carcass weight meat for i=B,P, and L.

i-NEXP = net exports in millions of pounds of ready-to-cook meat for i=C and T.

i-MCONS = military consumption in millions of pounds of carcass weight or ready-to-cook weight meat for the ith commodity where i=B,P,L,C, and T.

t = the current year.

General equation structure

Total civilian consumption for each subsector commodity is estimated by a behavioral identity. Civilian consumption is later used as an explanatory variable in the retail price equation which is discussed in the next section. Ending year inventory, exports, and military consumption are subtracted from production, imports, and beginning inventory to arrive at civilian consumption. Imports, exports and military consumption enter
into the identities as exogenous variables while the other variables are
current or predetermined endogenous variables.

**Beef civilian consumption**

\[ B_{CCONS_t} = B_{PROD_t} + B_{INV_{t-1}} + B_{IMP_t} - B_{INV_t} - B_{EXP_t} - B_{MILCONS_t} \]  
\[ (14) \]

**Pork civilian consumption**

\[ P_{CCONS_t} = P_{PROD_t} + P_{INV_{t-1}} + P_{IMP_t} - P_{INV_t} - P_{EXP_t} - P_{MILCONS_t} \]  
\[ (15) \]

**Lamb civilian consumption**

\[ L_{CCONS_t} = L_{PROD_t} + L_{INV_{t-1}} + L_{IMP_t} - L_{INV_t} - L_{EXP_t} - L_{MILCONS_t} \]  
\[ (16) \]

**Chicken civilian consumption**

\[ C_{CCONS_t} = C_{PROD_t} + C_{INV_{t-1}} - C_{INV_t} - C_{NEXP_t} - C_{MILCONS_t} \]  
\[ (17) \]

**Turkey civilian consumption**

\[ T_{CCONS_t} = T_{PROD_t} + T_{INV_{t-1}} - T_{INV_t} - T_{NEXP_t} - T_{MILCONS_t} \]  
\[ (18) \]

**Retail Price**

The retail price equations are presented below along with variable
definitions and an explanation of theoretical considerations taken into
account in the estimation of each of the five retail price equations.

**Variable definitions**

The following variables are used in the retail price equations:
\(i-PR = \) the retail price in cents per pound deflated by the Consumer Price Index with 1967=1 for the \(i\)th commodity where \(i=B\) (choice beef), \(P\) (pork), \(L\) (choice lamb), \(C\) (chicken), and \(T\) (turkey).

\(i-CCONS = \) civilian consumption in millions of pounds of carcass weight or ready-to-cook weight meat for the \(i\)th commodity where \(i=B\) (beef), \(P\) (pork), \(L\) (lamb and mutton), \(C\) (chicken), and \(T\) (turkey).

\(INC = \) personal disposable income in billions of dollars deflated by the Consumer Price Index with 1967=1.


\(LNT = \) the natural log of time.

\(t = \) the current year.

**General equation structure**

The level of civilian consumption is predetermined in the context of the retail price equation of the model presented in this paper. This is true because production is determined by past prices and ending inventory is determined by variables such as production which are estimated in earlier equations. The other variables such as exports which enter into the civilian consumption identity are assumed to be exogenous and therefore fixed at a given level for any particular year. Once production and inventory are known, civilian consumption is known. The quantities available for civilian consumption of a particular commodity and its substitutes are given and the retail price adjusts to clear the market.
For this reason the retail price of a particular commodity is treated as the dependent variable with the quantity available for civilian consumption of that particular commodity and of its substitutes as independent variables.

Personal disposable income and a time trend also are included as explanatory variables. Personal disposable income is included to account for the increased purchasing power of the U.S. population over the sample period. The time trend accounts for variability in price caused by changes in consumer preferences as well as other unquantifiable influences which cause retail prices to increase or decrease over time.

As in the production equation, it is assumed that total adjustment to long-run equilibrium might not occur within one year. Imperfect knowledge, habit persistence, and over-adjustment are several reasons for allowing for the possibility of imperfect adjustment. Retail price lagged one year thus is used as an independent variable. The coefficient of adjustment \((\lambda)\) can be obtained by subtracting the coefficient for the lagged dependent variable from one.

The short-run price flexibility for an independent variable at the variable mean can be estimated by multiplying the coefficient for the independent variable by the ratio of the independent variable mean to the mean of the retail price. A price flexibility is defined as the percentage change in price for a 1 percent change in an independent variable, other variables held constant. It can be called the elasticity of price with respect to consumption or income. Price flexibilities are reported because retail price is the dependent variable. Elasticities of demand are more appropriate when consumption is the dependent variable [48, pp. 29-30].
The long-run price flexibility at the variable mean is derived by dividing the short-run price flexibility by the coefficient of adjustment.

It is expected that the coefficient for the quantity available for civilian consumption for a particular commodity will be negative implying a negatively sloped demand curve. The coefficients for substitute commodities also are expected to be negative. An increase in the quantity available for consumption of a substitute good should cause its price to decrease. A decrease in the price of a substitute causes a decrease in the demand for the specific good in question, i.e., shifts the demand curve to the left. This demand shift implies that the price will fall for a given quantity. Hence, the relationship between the quantity of a substitute good and the price of the good in question is negative.

The coefficient for \( \text{INC}_t \) could be positive or negative depending upon whether the commodity is an inferior or normal good. It is expected that for the five livestock and poultry commodities considered, the sign will be positive. A negative sign is possible, however.

Several retail price equations were estimated for each subsector commodity. Where incorrect signs were found certain variables were eliminated. Some variables were deleted if they were significant at only a very large probability level. However, some of these variable were not deleted if their signs were theoretically correct to allow linkage among subsectors.

The final retail price equations are presented below along with
relevant statistics. Again, the coefficients are analyzed with ceteris paribus implicitly assumed. Also, all price flexibilities reported are calculated at the variable means.

**Beef retail price**

\[
B-RP_t = 111.9256 - .0066B-CCONS_t - .0003P-CCONS_t + .1104INC_t \\
+ 2.4529T + .1945B-RP_{t-1}
\]

\( (10.349) \quad (4.076) \quad (1.980) \quad (1.980) \)

\( R^2 = .9100, \quad MSE = 3.0868, \quad DW = 2.0125. \)

The independent variables of equation 19 explain 91 percent of the variance in the retail price of beef. Beef consumption, income, and time have coefficients which are significant at the 1 percent probability level. The coefficient for \( B-RP_{t-1} \) is significant at the 10 percent level and the coefficient for pork consumption is nonsignificant at the 10 percent level.

The estimated coefficient of adjustment is obtained by subtracting the coefficient for lagged retail price from one. In this case it is .81. The short-run price flexibility of \( B-CCONS_t \) is -1.45 and in the long-run it is -1.79. Hence, an increase in the quantity available for civilian consumption by 10 percent in the short-run is predicted to be accompanied by a decrease in the beef retail price by 14.5 percent while in the long-run retail price is predicted to decrease by 17.9 percent.

A price flexibility which is higher in the long-run than in the short-run indicates that beef price is more responsive to changes in quantity in the long-run than in the short-run. Fuller and Ladd
[23, p.802] obtained similar results in their estimated retail price equations for beef and pork. These results would seem to contradict the usual argument which compare short-run and long-run demand curves. A possible explanation is that consumers over-react to changes in relative prices. A knowledge of the cyclical patterns of commodities such as beef might lead consumers to over-adjust in the shortrun. It is well known that beef prices follow cyclical patterns. Therefore, it is conceivable that when beef prices are low relative to prices of substitutes, consumers might consume more beef than they would if they knew that the current low relative price were to continue over many years. High beef prices might encourage consumers to consume less in anticipation of lower future prices than they would if they knew that the current high relative price of beef were to prevail in the future.

Pork consumption is retained, though nonsignificant, to allow a direct link between beef retail price and other commodities. Low cross-price flexibilities of -.04 in the short-run and -.05 in the long-run are as expected because of the nonsignificant coefficient.

The income price flexibility is .64 in the short-run indicating that a 10 percent increase in personal disposable income brings about a 6.4 percent increase in beef price. The long-run income price flexibility is .79.

Pork retail price

\[ P_{RP_t} = 102.0800 - .0064*P_{CCONS_t} - .0024*B_{CCONS_t} \]

\[ (14.017) \quad (4.654) \]
Variables which are significant at the 1 percent level are \( P_{\text{CONS}} \), \( B_{\text{CONS}} \), and \( \text{INC} \), while log time and lagged retail price are significant at the 5 percent level. These variables explain 95.52 percent of the variance in pork retail price.

The price flexibility with respect to pork consumption in the short-run is -1.11 while the long-run price flexibility is -1.33. Cross-price flexibilities with respect to beef consumption in the short and long-run are -0.66 and -0.79, respectively.

Price flexibilities with respect to income are 1.26 and 1.50 for the short and the long-run, respectively.

**Lamb retail price**

\[
L_{\text{RP}} = 63.9403 - 0.0171L_{\text{CONS}} - 0.0017P_{\text{CONS}} + 0.0006B_{\text{CONS}} + 0.573\text{INC} + 0.4682L_{\text{RP}},
\]

\[ R^2 = 0.9507, \quad \text{MSE} = 4.4568, \quad \text{DW} = 2.1614. \]

The coefficient for \( L_{\text{CONS}} \) is significant at the 5 percent level and the coefficient for \( L_{\text{RP}} \) is significant at the 1 percent level. The estimated coefficient of adjustment is 0.53 which together with the coefficient for \( L_{\text{CONS}} \) suggests a long-run price flexibility.
of -.26. The short-run price flexibility is estimated to be -.14. Both estimated flexibilities suggest that the lamb retail price is quite inflexible with respect to changes in the quantity of lamb and mutton in a given year.

The annual quantity of civilian pork consumption has an estimated coefficient which is significant at the 1 percent level while the coefficient for beef consumption is nonsignificant at the 10 percent level. Short-run cross price flexibilities are estimated to be -.23 and -.14, and long-run flexibilities are estimated at -.44 and -.26 for pork and beef consumption, respectively.

A coefficient significant at the 5 percent level suggests the lamb price flexibilities with respect to income are .33 and .61 for the short-run and long-run, respectively.

**Chicken retail price**

\[
C-RP_t = 77.9181 - .0069*C-CONS_t - .0010*B-CONS_t - .0013*P-CONS_t - .0130*T-CONS_t + .1719*INC_t - 9.6243*LNT_t,
\]

\[(4.268) \quad (2.227) \quad (3.231) \quad (2.267) \quad (8.607) \quad (8.632)\]

\[\hat{R}^2 = .9871, \quad \text{MSE} = 2.1015, \quad \text{DW} = 2.4683.\]

Lagged chicken retail price is nonsignificant and is excluded from the equation. The implications are that the coefficient of adjustment is equal to one and the short-run and long-run price flexibilities are not significantly different from one another, i.e., perfect adjustment to long-run equilibrium occurs within one period.
All coefficients of the variables estimated are significant at the 1 percent level except for B-CCONS$_t$ and T-CCONS$_t$ which have coefficients significant at the 5 percent probability level. The chicken retail price flexibility with respect to the quantity of chicken is -.95 implying that an increase in quantity by 10 percent causes a decrease in chicken retail price by 9.5 percent. Chicken cross-price flexibilities with respect to the quantities of beef, pork, and turkey are -.41, -.34, and -.39, respectively.

The retail price flexibility with respect to income of 1.87 suggests that an increase in personal disposable income by 10 percent, based on observations of past consumer behavior, is accompanied by an increase in the retail price of chicken by 18.7 percent.

**Turkey retail price**

\[
T\text{-RP}_t = 93.1779 - 0.0261*T\text{-CCONS}_t - 0.0024*B\text{-CCONS}_t
\]

\[
- 0.0114*L\text{-CCONS}_t + 0.1018*INC_t
\]

\[
(2.577) \quad (2.940) \quad (1.467) \quad (2.995)
\]

\[R^2 = 0.8892, \quad MSE = 6.6734, \quad DW = 2.0632.\]

Again, lagged retail price is nonsignificant and adds little to the explanation of the variance in current turkey retail price. Therefore, it is dropped from the equation. Short-run and long-run price flexibilities are assumed to be equal.

The coefficient for T-CCONS$_t$ is significant at the 5 percent level suggesting a price flexibility of -.74. An increase in the quantity
of turkey available to consumers by 10 percent causes turkey retail price to decline by 7.4 percent.

The coefficients for $B_{\text{CONS}}$ and $L_{\text{CONS}}$ are significant at the 1 percent and 10 percent probability level, respectively. The cross-price flexibility with respect to beef consumption is estimated to be $-0.93$ and for lamb and mutton consumption it is estimated to be $-0.16$. The income price flexibility is estimated at 1.02.

The independent variables explain 88.29 percent of the variance in turkey retail prices over the 1956-76 sample period.

**Farm-Retail Margin and Gross Farm Value Identity**

The farm retail margin equations and the gross farm value identities are presented in the pages which follow. The first subsection contains definitions of variables used in these equations. Then the general structure of the simultaneous block of equations is delineated. For each subsector commodity the farm-retail margin structural and reduced form equations are presented with accompanying statistics. Lastly, the gross-farm value identity is presented.

**Variable definitions**

The variables which follow are used in the farm-retail margin structural or reduced form equations or in the gross farm value identities:

$$i_{-\text{FRM}} = \text{the farm-retail margin in cents per pound of meat sold at the retail level for the } i^{th} \text{ commodity deflated by the Consumer Price Index } 1967=100 \text{ where } i=B(\text{choice beef}),$$
i-RP\textsubscript{t} = the retail price in cents per pound of the \textit{i}th commodity deflated by the Consumer Price Index 1967=100 where \textit{i}=B, P, L, C, and T.

L-BYPROD\textsubscript{t} = amount paid to farmers in cents per pound for byproducts not sold as meat at the retail level deflated by the Consumer Price Index 1967=100 for \textit{i}=B, P, and L (i-BYPROD = 0 for \textit{i}=C and T).

i-FP\textsubscript{t} = the amount paid farmers for a quantity of live animal or bird equivalent to one pound sold at the retail level (gross farm value for \textit{i}=B, P, and L and farm value for \textit{i}=C and T) deflated by the Consumer Price Index 1967=100.

\textit{W} = the wage rate in dollars per hour for meat manufacturing employees deflated by the Consumer Price Index 1967=100.

i-PROD\textsubscript{t} = production in millions of pounds of carcass or ready-to-cook weight meat for the \textit{i}th commodity where \textit{i}=B (beef), P (pork), L (lamb and mutton), C (chicken), and T (turkey).

(\textit{MA4}) = a three-year, weighted, moving average of the accompanying variable where the weights are 1/4, 1/2, and 1/4.


\textit{LNT} = the natural log of \textit{T}.

\textit{t} = the current year.

Farm-retail margin and gross farm value identity general structure

The farm-retail margin is the difference between what consumers pay and what farmers receive per pound of meat sold at the retail level.
Payments to farmers for byproducts are excluded from the farm-retail margin. Charges for activities such as assembly, processing or packing, transportation, wholesaling and warehousing, and retailing are represented in the farm-retail margin [7, p.7].

The farm-retail margin and gross farm value are determined simultaneously. The price margin equation contains current gross farm value as an explanatory variable and the gross farm value is obtained by an identity which contains the current farm-retail margin. Ordinary least squares is rendered inappropriate because the simultaneity causes gross farm value to be correlated with the error term in the farm-retail margin equation. Therefore, two-stage least squares is used as the estimation technique.

The general form of the simultaneous system of structural equations is as follows:

\[
\begin{align*}
\text{i-FRM}_t &= a_0 + a_1 \text{i-ΔFP}_t + a_2 \text{W}_t + a_3 \text{i-PROD}_t + a_4 \text{i-BYPROD}_t + \text{U}_t, \\
\text{i-ΔFP}_t &= \text{i-FP}_t - \text{i-FP}_{t-1}, \\
\text{i-FP}_t &= \text{i-RP}_t - \text{i-FRM}_t + \text{i-BYPROD}_t,
\end{align*}
\]

where the a's are parameters to be estimated, \( \text{U}_t \) is a disturbance term, and all other variable are as defined earlier.

Equation 24 determines the farm-retail margin. The year-to-year change in gross farm value is included to account for a possible lag between changes in gross farm value and the retail price [1, p. 24]. A negative sign indicates that changes in retail prices lag behind changes in what farmers receive, while a nonsignificant coefficient
suggests that retail prices adjust within a year to changes in gross farm value.

Labor costs make up about half the total costs of meat marketing firms, excluding raw materials costs [9, p. 12]. A high degree of correlation exists among wage rates in different sectors of the marketing process. Therefore, the wage rate of meat manufacturing employees is used as a proxy for all wage rates. An increase in wage rates causes costs of marketing services to increase. Hence, the farm-retail margin which is a measure of marketing costs also increases. Therefore, a positive relationship between the farm-retail margin and the wage rate of meat manufacturing employees is postulated.

Current production is included in equation 24 to account for possible cost economies or diseconomies in providing marketing services. If the sign is negative, cost economies are implied. A positive sign suggests cost diseconomies.

Cost economies result in the providing of marketing services if increased production causes the cost per pound of meat processed to decline. Costs might decline as firms which perform marketing services are able to use existing capital and labor more efficiently, i.e., an increase in volume allows firms to work closer to capacity.

Cost diseconomies result (implying a positive coefficient for production) if an increase in meat production causes the cost per pound of performing marketing services to increase. Diseconomies result with increased production if firms are already operating close to capacity.
and therefore bid up the prices of resources, causing the cost of providing marketing services to increase.

A positive relationship between the byproduct allowance and the farm-retail margin is expected because of the identity expressed in equation 26. Equation 26 is simply a behavioral identity which must hold true because of variable definitions. Equation 25 defines the change in gross farm value.

The system of three equations and three unknowns (equations 24, 25, and 26) can be reduced to a system of two equations and the two unknowns by substituting equation 25 into equation 24. The resulting system can be solved for the two endogenous variable each being a function of all of the exogenous and predetermined endogenous variables in the system. The reduced form equation for the farm-retail margin is given as:

$$ i\text{-FRM}_t = \frac{a_0}{1+a} + \frac{a_1}{1+a_1} * i\text{-RP}_t - \frac{a_1}{1+a_1} * i\text{-FP}_{t-1} $$

$$ + \frac{a_2}{1+a_1} * W_t + \frac{a_3}{1+a_1} * i\text{-PROD}_t + \frac{a_1+a_4}{1+a_1} * i\text{-BYPROD} \quad (27) $$

The reduced form equation for $i\text{-FP}_t$ is obtained by substituting equation 27 into equation 26. In the computer simulation model equation 27 is solved first, and with $i\text{-FRM}_t$ estimated, equation 26 is solved directly by substituting the estimated farm-retail margin for $i\text{-FRM}_t$. 
The estimated structural equation and the derived reduced form equation for the farm-retail margin and the gross farm value identity for each commodity are presented below. The structural farm-retail margin equations are presented because of the statistics associated with them. They are not part of the computer simulation model as are the derived reduced form farm-retail margin equation and the gross farm value identity.

The equations for some subsectors have been modified and the structure changed when coefficients estimated in the initial equations had theoretically incorrect signs or were significant only at high probability levels. The coefficients are analyzed in the text assuming other variables are constant.

**Beef farm-retail margin structural equation**

\[
B-\text{FRM}_t = -12.0518 - 0.1713*B-\Delta FP_t + 16.4042*W(\text{MA4})_t \\
\quad - 0.004*B-\text{PROD}(\text{MA4})_t + 1.1343*B-\text{BYPROD}_t \\
\quad (6.270) \quad (6.213) \quad (2.671) \quad (5.122)
\]

Equation 28 is estimated with the specification portrayed in equation 25 with the exception of the weighted moving averages for \( W_t \) and \( B-\text{PROD}_t \). The coefficient for \( W(\text{MA4})_t \) is significant at the one percent level and the positive sign indicates, as expected, that increased wage rates cause the farm-retail margin to increase. The weighted three-year moving average is used to account for lags in the
effects of increased costs on the farm-retail margin. Implications are that costs associated with increased wages are not passed on to consumers or farmers within one year. Other specifications of W were less significant and explained less of the variance in B-FRM as indicated by higher mean square errors.

The coefficient for B-PROD(MA4)\_t is negative and significant at the 5 percent level indicating that costs economies exist in performing marketing services for beef. The weighted three-year moving average is used because it improves the explanatory value of the equation. The implications are that either decreases in per unit costs associated with increase volume are not passed on within one year or that the cost reducing effects of increased production do not occur completely within one year, or some combination of the above.

The change in gross farm value has a negative coefficient which is significant at the 1 percent level, and the coefficient for B-BYPROD\_t is also significant at the 1 percent level with a positive sign. An increase in the byproduct allowance for beef by 1 cent per pound causes beef farm-retail margin to decline by 1.13 cents per pound.

The Durbin-Watson statistic of 1.62 falls in the inconclusion region at the 5 percent level of significance. The mean square error is the lowest obtained from two-stage least square estimation for this equation.
Beef farm-retail margin reduced form equation

\[
B_{\text{FRM}}_t = -14.5434 - 0.2067B_{\text{RP}}_t + 0.2067B_{\text{FP}}_{t-1} + 19.7956W(MA3)_t - 0.0005B_{\text{PROD}(MA4)}_t + 1.1621B_{\text{BYPROD}}_t. 
\]  
(29)

Beef gross farm value identity

\[
B_{\text{FP}}_t = B_{\text{RP}}_t - B_{\text{FRM}}_t + B_{\text{BYPROD}}_t. 
\]  
(30)

Pork farm-retail margin structural equation

\[
P_{\text{FRM}}_t = 5.5844 - 0.1087P_{\Delta FP}_t + 16.9263W(MA3)_t - 0.0014P_{\text{PROD}(MA3)}_t - 0.2654T, 
\]  
(3.918)  
(3.984)  
(5.938)  
(2.569)  
(31)

\[ \text{MSE} = 0.7381, \text{ DW} = 2.4252. \]

The change in the gross farm value of pork is significant at the 1 percent level and the sign is negative suggesting that the retail price of pork lags behind changes in gross farm value. An increase in \( P_{\Delta FP}_t \) by 10 cents brings about a decrease in the farm-retail margin by 1.09 cents per pound.

Coefficients for \( W(MA4)_t \) and \( P_{\text{PROD}(MA4)}_t \) are significant at the 1 percent probability level. The signs and the statistical significance of the coefficients suggest that cost economies exist in pork marketing and that changes in current costs have effects on the farm-retail margin of pork in current and future periods.
The byproduct allowance is not included because initially it was estimated with a negative sign which seems unreasonable. Time is instead included to account for factors which have caused deflated pork farm-retail margin to decline. The coefficient for time is significant at the 5 percent level.

Pork farm-retail margin reduced form equation

\[ P_{FRM_t} = 6.2655 - .1219P_{RP_t} - .1219P_{BYPROD_t} + .1219P_{FP_{t-1}} + 18.9905W(MA4)_t - .0016P_{PROD(MA4)_t} - .2978T. \]  \hspace{1cm} (32)

Pork gross farm value identity

\[ P_{FP_t} = P_{RP_t} - P_{FRM_t} + P_{BYPROD_t}. \]  \hspace{1cm} (33)

Lamb farm-retail margin

\[ L_{FRM_t} = 19.8530 - .0125L_{PROD(MA4)_t} + .7137L_{FRM_{t-1}} \]  \hspace{1cm} (34)

\[ R^2 = .8585, \quad MSE = 2.2817, \quad DW = 1.6616. \]

The change in gross farm value and the absolute level of gross farm value were both nonsignificant and therefore excluded from the final equation. Because of the lack of simultaneity between the lamb farm-retail margin and the gross farm value identity, ordinary least squares was used instead of two-stage least squares. The wage rate of meat manufacturing employees and the byproduct allowance were also found to be nonsignificant and were excluded from the equation.
The two variables which explain the farm-retail margin for lamb are \( L-\text{PROD(MA4)}_t \) and \( L-\text{FRM}_{t-1} \). Both are significant at the 1 percent level. Together, these variables explain 85.85 percent of the variation in lamb farm-retail margin.

**Lamb gross farm value identity**

\[
L-\text{FP}_t = L-\text{RP}_t - L-\text{FRM}_t + L-\text{BYPROD}_t. \tag{35}
\]

**Chicken farm-retail margin structural equation**

\[
C-\text{FRM}_t = 9.1250 + 0.1815 \times C-\text{FP}_t + 0.0027 \times C-\text{PROD}_t - 0.9038 \times T, \tag{36}
\]

\[\text{MSE} = 0.4306, \quad \text{DW} = 1.4581.\]

In equation 36, \( C-\text{FP}_t \) is the current farm value per pound of ready-to-cook chicken, i.e., the amount paid to farmers for a quantity of live chicken equivalent to one pound of ready-to-cook chicken. The change in chicken farm value is excluded because of nonsignificance, implying that the retail price of ready-to-cook chicken adjusts rapidly to changes in farm value. The significance of the coefficient for \( C-\text{FP}_t \) at the 1 percent level and its positive sign suggest that chicken farm-retail margin is a constant percentage of farm value. An increase in farm value causes an increase in farm-retail margin if farmers and marketing firms receive constant percentages of the retail price. A positive relationship between farm value and farm-retail margin is most likely in an industry
which exhibits a low degree of competition. The broiler industry is an industry which in recent years is characterized by a large degree of vertical integration, contractual production, and formula pricing [29].

The coefficient for $C_{PROD_t}$ is significant at the 1 percent level. The positive coefficient suggests that cost diseconomies prevail in the marketing of chicken. Increased production is accompanied by an increased farm-retail margin as providers of marketing services bid up the prices of scarce resources. During the 1953-76 period, costs of wholesaling and retailing broilers increased as production increased [3, pp. 38-39].

The time trend is significant at the one percent level. Chicken farm-retail margin is predicted to decrease by .9 cents per pound per year.

**Chicken farm-retail margin reduced form equation**

$$C_{FRM_t} = 7.7232 + .1536*C_{RP_t} + .0023*C_{PROD_t} - .7649*T_t. \tag{37}$$

**Chicken farm value identity**

$$C_{FP_t} = C_{RP_t} - C_{FRM_t}. \tag{38}$$

**Turkey farm-retail margin structural equation**

$$T_{FRM_t} = -22.9909 - .1815*T_{\Delta FP} + 22.8894*W(\text{MA4})_t + 7.3387*LNT_t \tag{39}$$

$$MSE = 2.2555, \quad DW = 2.5344.$$
The change in the farm value of turkey is significant at the 1 percent level. Holding other things constant, a change in farm value by 10 cents per pound brings about a decrease in the farm-retail margin by 1.8 cents per pound.

The coefficient for $W(\text{MA}_4)_t$ is significant at the 5 percent level and the coefficient for LNT is nonsignificant at the 10 percent level. The natural log of time is left in the equation because it improves the fit greatly. The mean square error is high and the Durbin-Watson statistic is the inconclusive range. However, it indicates a possibility of negative autocorrelation among the errors.

**Turkey farm-retail margin reduced form equation**

\[
T-\text{FRM}_t = -28.0893 - 0.2218T-\text{RP}_t + 0.2218T-\text{FP}_t - 1 + 27.9653W(\text{MA}_4)_t - 8.9661\times\text{LNT}.
\]  

(40)

**Turkey farm value identity**

\[
T-\text{FP}_t = T-\text{RP}_t - T-\text{FRM}_t.
\]  

(41)

**Cash Receipts**

The cash receipts equations, which are the final five equations of the model, are presented in this section. The variables used in their estimation are listed and defined, followed by a general theoretical basis for estimating cash receipts. The equations for each subsector are then presented.
Variable definitions

The data for the following time series variables were used to estimate the cash receipts equations for the model:

\[ i-CR = \text{cash receipts in thousands of dollars from the sale of the } \]
\[ \text{ith commodity deflated by the Consumer Price Index 1967}=100 \]
\[ \text{where } i=B(\text{cattle and calves}), P(\text{hogs}), L(\text{sheep and lambs}), \]
\[ \text{C(\text{broilers and farm chickens}), and } T(\text{turkeys}). ]^{10} \]

\[ i-PROD = \text{production in millions of pounds of carcass or ready-to-} \]
\[ \text{cook meat for the ith commodity where } i=B(\text{beef}), P(\text{pork}), \]
\[ \text{L(\text{lamb and mutton}), C(\text{chicken}), and } T(\text{turkey}). \]

\[ i-FPC = \text{gross farm value in cents per pound of carcass weight} \]
\[ \text{equivalent meat deflated by the Consumer Price Index 1967}= \]
\[ 100 \text{ for the ith commodity where } i=B(\text{choice beef}), P(\text{pork}), \]
\[ \text{L(\text{choice lamb}). } I-FPC \text{ is the amount paid farmers for a} \]
\[ \text{quantity of live animal equivalent to one pound of carcass} \]
\[ \text{weight meat.} \]

\[ i-FP = \text{farm value in cents per pound of ready-to-cook meat for the} \]
\[ \text{ith commodity where } i=C(\text{chicken}) \text{ and } T(\text{turkey}). \]

\[ t = \text{the current year.} \]

---

\[ ^{10} \]

C-CR and T-CR contain the value of consumption of broilers by producers and the value of home consumption of turkey.
General equation structure

An important part of the economic analysis of any agricultural sector or subsector is income generation. The income generated by the sale of any of the livestock and poultry subsector commodities could be obtained by estimating another equation for the quantity sold and then estimating cash receipts as the product of the quantity sold and the farm price. Rather than estimate quantity sold, this study estimates cash receipts directly as a function of value of production (quantity produced multiplied by the farm price). The farm price is the price received by farmers per pound of live animal or bird. Farm price is obtained by dividing gross farm value by a conversion factor which converts gross farm value to a live-weight price. In practice, rather than convert production from carcass to live weight and gross farm value from retail weight equivalent to live weight equivalent, gross farm value is converted to carcass weight equivalent and multiplied by production in carcass weight pounds. The result is the same as if both were expressed in live weight equivalent. No conversion is needed for chicken or turkey because both farm value and production are expressed in ready-to-cook weight equivalent [9].

Cash receipts for cattle and calves

\[
B-\text{CR}_t = -898.4590 + 1.4443 \times (B-\text{PROD}_t \times B-\text{FPC}_t), \quad \hat{\beta} = .4197, \quad (42)
\]

\[
R^2 = .8814, \quad \text{MSE} = 869811.0704, \quad \text{DW} = 1.6509.
\]

\[\hat{\beta}\] is the estimated first order autoregressive parameter and the number in parentheses below it is a t-statistic.
The coefficient for beef value of production is significant at the 1 percent level and the estimated first order autoregressive parameters is significant at the 10 percent level. Equation 42 was first estimated by ordinary least squares, but estimation by autoregressive least square reduced the mean square error by 109,606 and increased the $R^2$ from .86 to .88.

Cash receipts for hogs

\[ P_{-CR_t} = 66.6524 + .7496 * (P_{-PROD_t} * P_{-FPC_t}), \quad \hat{\rho} = .8082, \quad (25.055) \quad (3.894) \]

\[ R^2 = .9790, \quad MSE = 8927.1690, \quad DW = 2.1501. \]

The product of $P_{-PROD_t}$ and $P_{-FPC_t}$ yields an estimated coefficient of .75 which is significant at the 1 percent level. The estimated autoregressive parameter is also significant at the 1 percent level. The equation explains approximately 98 percent of the variance in cash receipts from the sale of hogs.

Cash receipts for sheep and lambs

\[ L_{-CR_t} = -7.1480 + 1.1412 * (L_{-PROD_t} * L_{-FPC_t}), \quad \hat{\rho} = .5635, \quad (7.876) \quad (2.907) \]

\[ R^2 = .9336, \quad MSE = 203.7050, \quad DW = 1.8380. \]
The equation explains 93.36 percent of the year-to-year variation in cash receipts from the sale of sheep and lambs. The coefficient for value of production is significant at the 1 percent level, as is the estimated autoregressive parameter.

Cash receipts for chicken

\[ C-CR_t = 18.2104 + 0.8786(C-PROD_t \cdot C-FP_t), \quad \hat{\rho} = 0.9207, \quad (23.924) \quad (7.202) \]

\[ R^2 = 0.9773, \quad MSE = 1570.8668, \quad DW = 1.4875. \]

Both the coefficient for the product of C-PROD\_t and C-FP\_t and the coefficient for the estimated autoregressive parameter are significant at the 1 percent level. The high level of significance and the magnitude of \( \hat{\rho} \) indicate that the year-to-year error terms are highly correlated. Equation 45 explains 97.73 percent of the variability in chicken cash receipts.

Cash receipts for turkey

\[ T-CR_t = -33.5058 + 1.0621(T-PROD_t \cdot T-FP_t), \quad (10.740) \]

\[ R^2 = 0.8650, \quad MSE = 725.0636, \quad DW = 2.0161. \]
Turkey value of production explains 86.5 percent of the variance in cash receipts from the sale of turkeys. The Durbin-Watson statistic indicates no autocorrelation at the 1 percent significance level. The equation estimated by autoregressive least square resulted in a non-significant estimated autoregressive parameter. Therefore, the ordinary least squares equation is presented.

MODEL VALIDATION

Questions of model credibility and adequacy are now discussed. These questions of model validation deal with how well the model predicts against real world situations. One method of model validation is a comparison between the predicted results and the actual data from the system the model simulates. The closeness with which the model predicts reality provides a criterion for judging the adequacy with which it performs its purpose [2, pp. 17-18]. Model validation is somewhat a subjective process because the purpose behind modeling serves as a criterion in appraising the model's acceptability. Anderson [2, p. 18] summarizes the subjective nature of model validation:

Assessment of the acceptability of a model must take into account the purpose of modeling, which is tantamount to saying that validity is a subjective concept. What is an acceptable validation for one simulator will be viewed by his critics as, foolhardy contempt for reality.
The main purpose of modeling the livestock and poultry sector is to provide a model for analysis of agricultural policies. A valid policy model must represent the real world reasonably well. Its structural and behavioral relationships should conform closely with economic theory and coefficients should be estimated by appropriate statistical techniques [34, p. 26].

The correctness of the livestock and poultry model with respect to economic theory and statistical methods has been discussed in prior sections. The remainder of this section deals with the model's ability to mimic actual data from the livestock and poultry sector.

The accuracy with which the model tracks observed data is based upon a historical run for the 1958 through 1975 period. Actual exogenous data are employed to estimate the 34 endogenous variables.

Observed and predicted data are compared by presenting the actual and predicted times series along with percentage prediction errors for each year. Average absolute percentage prediction errors are also presented for each of the 34 endogenous variables.

A Theil inequality coefficient is formed for each endogenous variable whereby the model's predicting ability is compared with that of a naive model. The Theil coefficient used in this analysis is defined as

\[ U_2^2 = \frac{1}{N} \sum (A_t - \hat{P}_t)^2 \]

\[ \frac{1}{N} \sum (A_t - A_{t-1})^2 \]

(95)

12The Theil-\( U_2^2 \) coefficient was chosen as opposed to \( U_1^1 \) [42, p. 32] because of its advantages and clarity. \( U_2 \) is easily interpreted and provides a built in comparison with the naive no-change extrapolation. The interpretation of \( U_1 \), on the other hand, is clouded and the value it takes on is not uniquely determined by the mean square prediction error as is the case for \( U_2 \). For further information see [41, 28].
where $A_t$ is the actual observation in year $t$; $P_t$ is the predicted value in year $t$; $A_{t-1}$ is actual observation in year $t-1$; and $n$ is the number of observations being predicted. The numerator is an estimate of the expected mean square prediction error and the denominator is such that the prediction made by the model can be compared with a naive no-change extrapolation. A naive no-change extrapolation is a model for which $P_t$ is set equal to $A_{t-1}$, i.e. The prediction in the current year is set equal to last year's actual value. Perfect prediction is signified by a $U_2^2$ equal to zero which is also the coefficients lower bound. A Theil coefficient greater than one suggests that the naive no-change extrapolation predicts better than the model being considered while a coefficient less than one implies that the model under study predicts better [24, 41].

An analysis of the historical validation run is detailed for each of the seven endogenous variable types in the following sections. Tables 1 through 7 contain actual, predicted, and percentage prediction errors for the seven variable types. Table 8 displays the 18 year average absolute percentage errors for each variable and Table 9 presents the Theil-$U_2^2$ inequality coefficients. Tables 1 through 9 are found in Appendix C.

Production

Predicted production of the five livestock and poultry commodities corresponds quite closely with actual production level. The percentage error in predicted beef production ranges from an underestimation of 4.5 percent in 1960 to an overestimation of 3.6 percent in 1972. The average absolute prediction error is only 2.2 percent for the 18 year period.
Beef production is persistently underestimated during the 1964 through 1970 period and overestimated from 1971 through 1975. The apparent autocorrelation can be explained by the small coefficient of adjustment. When production is estimated with error in the current period, the error is carried into the next period through the lagged dependent variable. If the coefficient for the lagged dependent variable is large (as in the case of lagged beef production) then the current year's error takes several years to work itself out as equilibrium is again approached.

The average absolute prediction error is 3.9 percent for pork and only 1.7 percent for chicken. Pork production is predicted with errors ranging between -8.8 to 6.8 percent. The range in percentage errors for chicken is from -5.4 to 4.1.

The model predicts lamb production reasonable well after 1964. Underpredictions for 1961 and 1962 are 14.1 percent and 11.8 percent, respectively. The largest overprediction is 5.5 percent in 1969. The average absolute prediction error for the analysis period is 4.4 percent which is only exceeded among the production variables by turkey with a value of 5.1 percent.

The Theil inequality coefficients for the production variables indicate reasonable forecasting accuracy in relation to the naive model. Lamb production is an exception, however. The $U_2$ coefficient of 1.27 suggests that lamb production would be more accurately predicted by

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13 Negative percentage prediction errors represent overpredictions while positive percentage prediction errors represent underpredictions.
the no-change extrapolation, i.e., by setting this year's predicted production equal to last year's actual production. The question might be asked, should the naive model be substituted for the estimated econometric equation for lamb production? The answer depends upon the purpose for modeling. If one were concerned with predicting lamb production alone, the naive model is more useful because it is more accurate. If the modeling objective is to analyze the impact of government policies upon lamb production, the econometric model is more useful because it is estimated with price variables through which policy impacts can be traced. The naive model uses only lagged production to predict current production. Therefore, the lamb production equation presented earlier in this paper is retained even though it predicts somewhat less accurately than the naive model.

Inventory

Table 2 contains actual inventory, predicted inventory, and percentage errors of prediction for each of the four livestock and poultry commodities. Inventories are predicted with less accuracy than are the levels of production for these four commodities. The error in beef inventory ranges from an underprediction of 19.6 percent to an over-prediction 13.3 percent. The average absolute error is 8.0 percent. Turkey inventory is predicted with the least amount of accuracy as is indicated by a range in percentage prediction errors from -46.9 to 30.7 percent for individual years and an average absolute prediction
error of 18.2 percent. The absolute percentage errors for pork and lamb are 17.1 and 14.9, respectively.

Despite the relatively poor performance of the inventory econometric equations with respect to percentage error, the $U_2^2$ coefficients presented in Table 8 suggest that the model equations are better predictors than the naive no-change extrapolations. Beef has the lowest Theil statistic of .35, while turkey has the highest of .72.

Consumption

Chicken consumption is predicted with the greatest amount of accuracy. The average absolute percentage error is 1.8 as compared to the high of 3.9 percent for pork consumption. However, the range in percentage error is smallest for beef consumption which is underestimated in 1960 by 4.7 percent and overestimated in 1972 by 3.3 percent. Chicken consumption has the next smallest range of between -5.7 percent to 4.3 percent.

The Theil coefficients for the consumption variables are all less than one and reasonably low. The $U_2^2$ statistic for lamb consumption is the highest (.49), while that for chicken consumption is the lowest (.19).

Retail Price

Retail prices are predicted with average absolute errors of 4.4 percent, 4.3 percent, 2.2 percent, 3.0 percent, and 4.4 percent for beef, pork, lamb, chicken and turkey, respectively. The beef retail price is
underestimated by 10.4 percent in 1972 and overestimated in 1968 by 7.8 percent. Errors for pork retail price range between -11.8 percent in 1964 and 8.7 percent in 1966. Lamb retail price which has the lowest average absolute percentage prediction error varies between -7.1 and 4.9 percent of actual retail prices. The model predicts chicken retail prices within the range of -7.7 percent and 7.9 percent and turkey retail prices within -11.6 percent and 7.5 percent.

The retail price of beef has a Theil coefficient of .87 which is less than but close to one. All other $u^2$ statistics are less than .5 with chicken retail price taking on the lowest value of .14.

**Farm-retail Margin**

Table 5 compares actual and predicted farm-retail price margins for the five commodities. The largest overprediction for the five commodities is 20.8 percent for turkey in 1959 and the largest under-prediction is 15.2 percent for turkey in 1961. The commodity with the smallest range in prediction error is chicken with a range between -5.4 percent and 3.7 percent. Chicken also has the lowest average absolute error of 2.1 percent.

Theil coefficients are fairly low except for lamb. The Theil coefficient of 1.22 for lamb farm-retail margin suggests that the naive model provides better estimates of the farm-retail margin for lamb than does the statistically estimated equation employed in the model presented in this paper. To provide interaction between subsectors, the econometric equation is retained. The values of $u^2$ for the other commodities are below .50.
Gross Farm Value

The mean absolute prediction error ranges from a low of 4.2 for lamb to a high of 8.9 for both turkey and pork. All of the Theil coefficients are less than one suggesting that the model presented predicts better than the naive model. All Theil coefficients except beef are less than .5. The $U_2^2$ coefficient for pork gross farm value is .18, while $U_2^2$ for beef is .63.

Cash Receipts

Cash receipts from the sale of cattle and calves has the highest mean absolute percentage error (8.9). The error ranges from an underestimate of 24.0 percent in 1972 to an overestimation of 26.2 percent in 1975. The high percentage errors are probably caused by inclusion of cash receipts for the sale of calves. Cash receipts for cattle are not reported separately from those of calves. Therefore, the independent variable, beef value of production, would be expected to produce a high degree of error in predicting cash receipts for cattle and calves.

Cash receipts from the sale of sheep and lambs has the lowest average absolute percentage error of 4.2 with a range from -11.0 percent to 10.0 percent.

The Theil coefficients for chickens, hogs, and turkeys are below .3, while those for sheep and lambs, and cattle and calves are .59 and .83, respectively. All of the cash receipts equations predict better than the naive model.
CONCLUDING REMARKS

The model presented in this paper was estimated by econometric techniques which are consistent with appropriate statistical methods. Tests for autocorrelation and for correlation of error terms among equations lead to the use of ordinary least squares, autoregressive least squares and two-stage least squares where appropriate.

The structure of the model is consistent with economic theory. Only variables with estimated coefficients having theoretically correct signs are retained in the model. The model is constructed to allow competition among the five subsector commodities. Linkages to the feed grain and soybean crop subsectors are modeled into the production equations to allow impacts on the livestock and poultry sectors from outside the model.

The livestock and poultry model is constructed for use in analyzing the impact of government policies. The closeness with which the model tracks the historical data and the magnitudes of the Theil-$U_2^2$ coefficients lead to the publication of this report and to the conclusion that the model is sufficiently accurate to allow its use in policy analysis.

The CARD (Center for Agricultural and Rural Development) national agricultural simulation model is currently being updated and revised. The revised model will contain feed grain, wheat, soybean, cotton, and tobacco crop sectors. The livestock and poultry sectors presented in
this report will be linked with the crop sector through the feed grain, wheat, and soybean subsectors. The model will be used to study direct and indirect effects of government policies on U.S. agriculture. The livestock and poultry model will play a major role in determining demands for feed grains, wheat, and soybeans.
SUMMARY

The government grain policies of the 1950s and 1960s were highly beneficial to the livestock and poultry sector. Feed prices were stabilized resulting in a higher degree of specialization in the livestock and poultry industries. However, the free market grain policies of the early 1970's reintroduced a high degree of uncertainty in feed prices. The livestock and poultry sector received little direct consideration as these policies were formulated.

The highly specialized agricultural sector which has evolved as a result of stabilizing government policies requires that the livestock and poultry sector be considered equally with the crop sector as agricultural policies are formulated. The livestock and poultry econometric model presented in this study can be used to analyze the impacts of agricultural policy upon the livestock and poultry sector. The model can be linked to existing crop models through the impact of feed grain and soybean price changes upon the production of livestock and poultry commodities. Other links can be made through the effects of livestock and poultry production upon the feed demands for feed grains, soybeans, and wheat.

The livestock and poultry econometric simulation model presented consists of five commodities: beef, pork, lamb, chicken and turkey. Each of these subsectors, except for chicken, is composed of seven equations, five of which are estimated by econometric methods while two are behavioral identities. Econometric equations are
estimated to predict production, end-of-year inventories, retail prices, farm-retail margins, and cash receipts. Chicken inventories are assumed to be exogenous because of lack of correlation with any of the hypothesized independent variables. Civilian consumption and gross farm value are determined by behavioral identities for each of the five subsectors.

The model is block recursive in structure. A block recursive model is one which consists of some endogenous variables which are determined sequentially while others are determined simultaneously. The production, inventory, civilian consumption, and retail price equations are solved sequentially in the computer model. The farm-retail margin and gross farm value equations form a simultaneous block which can only be solved after the retail price is determined by the preceding recursive equations. The cash receipts equation then follows as the remaining recursive equation.

Ordinary least squares is used as the econometric method for estimating most of the recursive equations while two-stage least squares is used to estimate the farm-retail margin equation which is simultaneous with the gross farm value identity. An autoregressive least squares method was tried for each recursive equation resulting in improved fits for only some of the cash receipts equations.

Annual time series data are used to estimate the econometric equations. The series used are from 1953 through 1976 in most cases. The farm value and farm-retail margin data for turkey include observations for the period 1956 through 1975, while the lamb gross farm value and farm-retail margin are estimated with data for 1953 to 1975, inclusive.
The five production equations are estimated in a distributed lag form by including lagged production as an independent variable. Incentives for farmers to produce are captured by including lagged gross farm value and lagged feed costs as independent variables. Feed costs are a weighted average feed grain and soybean price where the weights are based upon assumed protein rations for each livestock or poultry subsector commodity. In many instances two-or three-year moving averages of these price and cost variables are included.

The inventory equations are estimated by including a particular commodity's own current production as well as the sum of the current production of all other meats. This specification allows a certain amount of competition among the five commodities. A dummy variable with 1973 equal to one and zero for other years is included to account for the 1973 price freeze which is hypothesized to have caused meat packers to build up their cold storage inventories. In some cases coefficients for lagged inventory are negative, indicating an over adjustment to long-run equilibrium by meat packers.

Competition among livestock and poultry commodities also enters into the model through the retail price equations. The retail price of a particular commodity is estimated as a function of its own quantity as well as the quantities of competing meats. Personal disposable income deflated by the Consumer Price Index with 1967=100 and lagged price are also included as explanatory variables.
The farm-retail margin equations are estimated by including variables which are hypothesized to cause the costs of providing marketing services to vary. The average wage rate per hour of meat manufacturing employees is used to represent fluctuations in marketing costs due to labor costs. Cost economies and diseconomies are taken into account by including current production as an independent variable. To account for lags in adjustment in the farm-retail margin to changes in costs, three-year, weighted, moving averages of the wage rate and production are used in most equations, as opposed to the current values alone.

All cash receipts equations except for turkey are estimated with an autoregressive least squares model. The turkey equation is estimated with ordinary least squares.

The 34 equations are specified in a computer model written in the FORTRAN language. The model is verified and validated. Validation is based upon a historical run for the period from 1958 through 1975. The results are found in Tables 1 through 9 of Appendix C. The presentation of observed and predicted data, the percentage deviation of predicted from observed data, the average absolute percentage prediction error, and a form of Theil's Inequality Coefficient are four groups of data used to validate the model.
Average absolute prediction errors range from 1.7 percent for chicken production to 5.1 percent for turkey production. The average absolute percentage prediction errors for civilian consumption are lower than for production in all cases except for chicken and pork. The range is between 1.8 percent for chicken and 3.9 percent for pork. The retail price of lamb is predicted with the least error among the retail price variables. The average absolute prediction error is 2.2 percent while those for beef and turkey of 4.4 percent are the highest. The farm-retail margin for chicken is predicted with an error averaging 2.1 percent of observed farm-retail margin while turkey has the highest average absolute deviation of 6.8 percent. The average absolute percentage prediction errors for both prices received by farmers and cash receipts range between 4.2 and 8.9. The inventory equations are predicted with the least amount of accuracy with average absolute deviation between 8.0 percent for beef and 18.2 percent for turkey.

The Theil coefficients are all less than one except for lamb production and the lamb farm-retail margin. A coefficient of less than one indicates that the model equation predicts better than a naïve model where the current predicted value is set equal to last year's observed value of the endogenous variable. The lamb production and farm-retail margin equations are not replaced by the naïve model because the naïve model does not allow for the analysis of the impacts of government policies. The model would not fully meet the objective of the study if these two equations were replaced.
From the validation results it is concluded that the model predicts with sufficient accuracy to allow it to be used for policy analysis. It is to be linked to a revised and updated version of the national agricultural econometric simulation model at the Center for Agricultural and Rural Development (CARD).


APPENDIX A: FEED COSTS

The feed cost variables are weighted averages of the season average price received by farmers in dollars per ton for feed grains (FGP) and the season average price received by farmers in dollars per bushel for soybeans (SBP). The weights are obtained by assuming crude protein rations of 11 percent for beef, 14 percent for pork, 8.9 percent for lamb, 21 percent for chicken, and 16.5 percent for turkey [31]. One bushel of soybeans is assumed to yield 47.5 pounds of meal. Feed grains are assumed to contain 8.9 percent protein which is the protein content of number two yellow corn. Soybean meal is assumed to be 43.8 percent protein.

The season average feed grain price is a weighted average of season average prices received per ton by farmers for corn, oats, barley, and grain sorghum. The weights are the respective commodity productions in tons.

Feed costs per hundred pounds of feed is obtained by solving equations 1 and 2 simultaneously:

\[
\begin{align*}
\text{FG} + \text{SB} &= 100, \\
.089\times \text{FG} + .438\times \text{SB} &= i-R,
\end{align*}
\]

where FG and SB represent quantities in pounds of feed grains and soybeans, respectively, which satisfy the two equations and i-R is the ration requirement for the \( i \)th commodity where \( i = B \) (beef), \( P \) (pork), \( L \) (lamb), \( C \) (chicken), and \( T \) (turkey).
Feed costs are obtained by multiplying FG and SB by their respective prices. Equation 3 expresses feed costs per hundred pounds as a function of FGP and SBP.

\[ i-FC = \frac{FG}{2000} \times FGP + \frac{SB}{47.5} \times SBP, \]  

where all variables are as previously defined.

Feed grain price per ton is multiplied by FG converted from pounds to tons by dividing by 2000. Similarly, soybean price per bushel is multiplied by SB converted to bushels. The resulting feed cost variables are presented below:

\[
\begin{align*}
B-FC_t &= .047 \times FGP_{t-1} + .127 \times SBP_{t-1}, \\
P-FC_t &= .043 + FGP_{t-1} + .308 \times SBP_{t-1}, \\
L-FC_t &= FGP_{t-1}, \\
C-FC_t &= .033 \times FGP_{t-1} + .730 \times SBP_{t-1}, \\
T-FC_t &= .039 \times FGP_{t-1} + .458 \times SBP_{t-1}.
\end{align*}
\]

The subscript \( t \) refers to the current year.

Lagged feed grain and soybean prices are used because the crop year starts October 1 for feed grains and September 1 for soybeans. The year for all livestock and poultry variables starts January 1. Lagged feed grain and soybean prices included months through September or October of the current year whereas current feed grain and soybean prices include months from September or October through December of the current year. Therefore, lagged crop year feed grain and soybean
prices represent current prices better than do current crop year prices in relation to the livestock and poultry variables. As a consequence, the current feed cost variables are lagged three to four months from livestock and poultry production.
APPENDIX B: DATA SOURCES

The data sources from which data were taken to form annual time series are presented in this appendix for each commodity.

Beef, Pork and Lamb

Quantity variable (PROD, INV, CCONS, IMP, EXP, and MILCONS)

Sources: U.S.D.A. Food Consumption, Prices, and Expenditures [10].
U.S.D.A. Livestock and Meat Situation [12].

Price and cash receipts variables (FP, RP, FRM, BYPROD, and CR)


Chicken and Turkey

Quantity variables (PROD, INV, CCONS, NEXP, and MILCONS)

Sources: U.S.D.A. Food consumption, Prices, and Expenditures [10].
U.S.D.A. Poultry and Egg Situation [22].
Price and cash receipts variables (FP, RP, FRM, and CR)

Sources: U.S.D.A. Farm Retail Spreads for Food Products [9].
U.S.D.A. Marketing and Transportation Situation [16, 17, 17, 20, and 21].
U.S.D.A. Agricultural Outlook [44].
U.S.D.A. Farm Income Statistics [8].
U.S.D.A. Agricultural Statistics [45, 46].

Other Variables

Personal disposable income (INC)


Range feed conditions [RFC]

Source: U.S.D.A. Western Range and Livestock [39].
U.S.D.A. Western Range and Livestock, Monthly Reports [40].
U.S.D.A. Crop Production, Monthly Reports [38].

Consumer Price Index 1967=100


Index of prices paid by farmers 1967=100

Source: U.S.D.A. Agricultural Statistics [45, 47].

Wage rate of meat manufacturing employees (W)


Feed cost variables (FC)\(^1\)

Source: U.S.D.A. Agricultural Statistics [45, 47].

\(^1\) See Appendix A
APPENDIX C: TABLES 1–9
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**SOURCE:** Food Consumption, Prices, and Expenditures (1959).
### Table 2: Actual, Predicted, and Percentage Error for Inventories of Four Livestock and Poultry Commodities

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**Source:** Livestock and Meat Statistics (1314).

**Source:** Agricultural Outlook (94).

**Source:** Farm-Retail Spreads for Food Products (9).

**Source:** Marketing and Transportation Situation (18).

**Source:** Marketing and Transportation Situation (16, 17, 20, 21).
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**Sources:**
- Livestock and Meat Statistics (13, 14).
- Agricultural Outlook (94).
- Farm-Retail Spreads for Food Products (9).
- Marketing and Transportation Situation (16).
- Marketing and Transportation Situation (16, 17, 20, 21).
### TABLE 6. ACTUAL, PREDICTED, AND PERCENTAGE ERROR FOR GROSS FARM VALUES OF FIVE LIVESTOCK AND Poultry Commodities

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**SOURCES:**

- Livestock and Meat Statistics (13,14).
- Agricultural Outlook (99).
- Farm-Retail Spreads for Food Products (9).
- Marketing and Transportation Situation (10).
- Marketing and Transportation Situation (11,17,20,21).
## Table 7. Actual, Projected, and Percentage Error for Cash Receipts from the Sale of Five Livestock and Poultry Commodities

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### Footnotes:
- Source: Livestock and Meat Statistics (13, 14).
- Source: Farm Income Statistics (8).*
- Source: Agricultural Statistics (45, 46).
Table 8. Eighteen-year average absolute percentage errors for thirty-four variables

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\(^a\)The average absolute percentage prediction error is defined as
\[
APE = \frac{1}{18} \sum_{t=1}^{18} |A_t - P_t|,
\]
where \(A_t\) is the actual observation in year \(t\) and \(P_t\) is the predicted value in year \(t\).

\(^b\)Gross farm value for beef, pork and lamb and farm value for chicken and turkey.

Table 9. Theil inequality coefficients \((U_2^2)\) for thirty-four variables

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APPENDIX D: TEST FOR CORRELATED ERRORS

Assume the following two equation model:

\[ Y_1 = X_1 \beta_1 + U_1, \quad (1) \]
\[ Y_2 = Y_1 \gamma_2 + X_2 \beta_2 + U_2, \quad (2) \]

where \( Y_1 \) and \( Y_2 \) are endogenous variables, \( U_1 \) and \( U_2 \) are stochastic errors, \( X_1 \) and \( X_2 \) are exogenous and predetermined variables in equations 1 and 2, respectively, and \( \beta_1, \beta_2, \) and \( \gamma_2 \) are parameters to be estimated.

The ordinary least squares residual for equation 1 is:

\[ \hat{U}_1 = (1 - X_1 (X_1' X_1)^{-1} X_1') Y_1, \quad (3) \]

where \( \hat{Y}_1 = X_1' (X_1 X_1')^{-1} X_1' Y_1 \).

Substituting \( X_1 \beta_1 + U_1 \) from equation 1 for \( Y_1 \) in equation 3 gives

\[ \hat{U}_1 = (1 - X_1 (X_1' X_1)^{-1} X_1') \hat{U}_1. \quad (4) \]

If the covariance of \( U_1 \) and \( U_2 \) equals zero then the covariance of \( \hat{U}_1 \) and \( U_2 \) equals zero and the expected value of the regression coefficient for \( \hat{U}_1 \) in equation 5 is zero because \( \hat{U}_1 \) is a linear transformation of \( U_1 \).

\[ Y_2 = \hat{U}_1 \delta_2 + Y_1 \gamma_2 + X_2 \beta_2 + U_2. \quad (5) \]

Thus it follows that a t-statistic for the coefficient of \( \hat{U}_1 \) is a test of the hypothesis that \( U_1 \) and \( U_2 \) are uncorrelated.\(^1\)

\(^1\) The contents of Appendix D were taken from a memo received by the authors on February 21, 1979 from Wayne A. Fuller, professor of statistics at Iowa State University.
Acknowledgements

Several persons have contributed to the completion of this report. Professor Wayne A. Fuller deserves special thanks for his statistical counsel and guidance. Professors Gene A. Futrell and Ronald Raikes freely contributed of their expertise in livestock and marketing as the model structure was developed.

The model structure and statistical results are the sole responsibility of the authors and are not intended to represent the views of the individuals mentioned in the acknowledgements.

Roland A. Roberts
Earl O. Heady
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