CARD Livestock Model Documentation: Poultry

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The U.S. poultry industry is the fastest growing sector within the meat complex. Concentration and efficiency of U.S. poultry production have grown steadily since the mid-1930s. Poultry is the most vertically integrated of the meat industries and vertical coordination, the linking together of successive stages of production and marketing through ownership or contracting, has spread rapidly, allowing poultry producers to maintain lower per-unit production costs and higher profits relative to those in other meat industries. Virtually all commercial poultry is grown under contract or by integrated firms. Due to the vertical integration, production decisions, from the hatchery supply flock through final production, are made by vertically coordinated management. This allows for the analysis of poultry production as part of a single production process, unlike beef and pork production.

Increasing concentration of poultry production in large capital-intensive operations has occurred in the past 15 years. Farms with sales of more than 100,000 broilers accounted for almost 70 percent of the total number of broilers sold and 43 percent of turkeys sold in 1974 (U.S. Bureau of the Census 1974); eight years later, they accounted for nearly 89 percent of the total number of broilers sold and 53 percent of turkeys (U.S. Bureau of the Census 1982).

Nevertheless, some constancies remain in the U.S. poultry industry. Poultry production remains regionally concentrated in the south Atlantic and south central states.[1] In 1980 nearly 88.2 percent of the U.S. broiler production and 40.8 percent of turkey production occurred in these southern states. Broiler output has declined in the northeastern states and north central states.[2]

Over the past decade the efficiency of poultry production has increased significantly with improvements in management, breeding, and technology. Since 1980 the average weight at slaughter has increased, the age at slaughter has dropped, and feed conversion ratios for broilers have declined. These changes have increased broiler feeding efficiency and kept broiler prices low relative to beef and pork prices.

The average consumer is eating more broiler and turkey meat than was the case earlier. For example, per capita consumption of broilers has increased dramatically from 32.8 pounds in 1968 to 56.7 pounds in 1987. This increase in per capita consumption of broilers was sustained by improved product quality and availability, and by relatively low retail prices. The expansion of processed broiler items for at-home consumption, increased fast-food choices, and development of poultry as an attractive, low-cost menu item all have helped to expand consumption.

Per capita consumption of turkey increased from 7.8 pounds in 1968 to 13.4 pounds in 1986. While consumption continues to remain high during the Thanksgiving and Christmas holiday seasons, increased production and productivity has helped to lower prices to consumers and boost year-round consumption.

This report presents quarterly econometric models of the U.S. broiler and turkey sectors. The models incorporate constancies within the sector, yet allow for technological change over time. The econometric models provide an abstraction of a complex system and aid in synthesizing information and causal relationships into a comprehensible form. Formalizing the behavioral relationships allows econometric models to be used as tools for analyzing changes in policy, technology, structure, and forecasting.

The U.S. quarterly poultry models are linked to other subsector models of the agricultural economy. These linkages are depicted in Figure 1. The broiler and turkey models are two of four econometric models developed at the Center for Agricultural and Rural Development (CARD), Iowa State University, to represent the major components of the livestock sector. The others, the quarterly beef and pork models, are described in greater detail in CARD Technical Reports 2 and 4 (Grundmeier et al. 1989 and Skold et al. 1989).

The poultry models are linked to the other livestock models through retail meat prices. This linkage assumes that cross-commodity effects originate on the demand side and result from consumers' adjustment to changes in relative retail prices. This ignores the cross-commodity linkages at the farm level. If sufficiently induced, producers could shift from poultry production to some other production enterprise. However, given the concentration of production and the capital-intensive production methods used throughout the poultry sector, the farm-level, cross-commodity effect is ignored.

The poultry models, like the other livestock models, are also linked to the annual feed grain models through the prices of corn and soymeal. The feedback to the annual feed-crop models is through grain-consuming animal units (GCAU), high-protein animal units (HPAU), and an index of livestock prices (LPI). These indices give a weighted measure of feed use and price movements, and provide a compact method of transferring livestock production and price information to the feed grain sectors and soybean complex. The parsimonious set of exogenous economic factors that influence the livestock sector in general, and the poultry sector in particular, are the interest rate, income through food expenditures, the inflation rate, and processors' marketing costs.

The econometric models of the poultry sector provide a complete depiction of the phases in the poultry production processes and of the primary demand categories. The supply components of the models track producers' breeding and hatchery flock expansion and contraction decisions. The supply components of the models are based on constancies in the growth process for broilers and turkey as well as on the economic considerations of poultry producers.

The demand component recognizes that in the very short run poultry production is essentially fixed and, thus, price determination is at the retail level. The demand component also recognizes that consumers' adjustment to changes in relative prices and income is not instantaneous. Habit formation and imperfect information flows are the reasons for the partial adjustment process. Consumers' inability to adjust fully implies that the precepts of consumer behavior do not hold in the short run.

However, in the demand structure the restrictions on consumer behavior are imposed in the long run, which in turn restricts consumers' short-run behavior.

The order of this paper is as follows: an overview of the models, the modeling approach used in contrast with previous econometric models of the poultry economy, background on the specification of the model and the estimation results, and, finally, the models' behavior compared with previous studies and validated with simulation statistics.

Model Overview

The U.S. quarterly poultry models provide a representation of the key behavioral relationships within the broiler and turkey industry. This section includes a brief overview of the structure and specification of the supply and demand components. The specification of each equation is further detailed in the estimation results section that follows.

The sequential phases in the poultry production process provide the benchmark for specifying the supply structures. These structures recognize that current supply is conditioned on past placements into the hatchery flock and hatching decisions. The size of the hatchery flock determines the industry's production capacity. The stages in production fall sequentially from the size of the hatchery flock.

The level of supply is dictated by the broiler or turkey placements in hatchery supply flocks. Since turkey placements are not reported, for the turkey model the turkey poults hatched from the hatchery supply flock are used as the measure of the placement of poults into the hatchery supply flocks. Chick placement and hatching equations are used as the basis for deriving broiler production estimates needed to support the broiler supply and use equations. Turkey production is estimated with no explicit placement equation; rather, poults hatched is the primary supply determinant. Also included in the broiler model is an equation for other chicken production. Other chicken production refers to total production of chicken except broilers. This equation reflects the producer's decision to disinvest or reduce the mature breeding flock in response to signals from the broiler market. The structure of the poultry models reflects the shorter biological production lags and the high degree of vertical integration in the broiler and turkey industries.

The level of the hatchery supply flock essentially determines the total commercial supply of chicken and turkey. Domestic disappearance is defined as the difference between total commercial supply and changes in other use categories. These categories include imports and exports, cold-storage stocks, and military use. These categories are treated as exogenous in the models. However, in the turkey model a behavioral equation is included for turkey ending stocks.

As with the other poultry and livestock models, the lag structure in the supply block is governed by the biological timetable in the sequential phases of the production process. The biological production sequence, set within the integrated industry structure, provides a benchmark in defining the lag length of explanatory variables in the supply components. Thus, the supply response is governed by the time lags in the placement, hatching, and slaughter production steps. Of course, the supply response is also dependent on producers' production decisions. A parsimonious set of input and output prices is included in the supply equation to reflect producers' conditioning variables. Seasonality is accounted for with quarterly dummy variables.

The production process for poultry is sequential, linking placement in the hatchery supply flock to production (Chavas 1978). Chicks (poults) coming from the primary breeder flock are introduced in the hatchery supply flock. For broilers (turkeys), the hatchery supply flock in turn produces the chicks (poults) that are fed and subsequently sold for human consumption. Placement can refer to the placement of just-hatched chicks or poults into the primary breeder flock, placement in the hatchery supply flock, or placement in the feeding flock.

Placement is determined by hatching rates as well as by other factors. The hatching rate of broiler-type chickens is about 80-85 percent of eggs set. The period from initial breeding to slaughter of offspring is about three months for broilers. A period of 26 days is required between the shipment of eggs to the hatchery and the placement of chicks (Rausser and Cargill 1970). Testing for pullorum disease occurs at the beginning of the laying cycle. The beginning of egg production occurs at approximately five months of age for broiler-type chickens. Eight weeks is required after placement into the feeding flock to produce a 3.8 pound broiler, live weight (72 to 73 percent dressing).

The turkey production process is very similar to that of broilers. The beginning of egg production occurs at about six months of age for turkeys. The length of the production cycle is six to seven months for turkeys. Seventeen weeks is required after placement into the feeding flock to produce a 14.5-pound hen turkey, live weight (80 percent dressing), and 21 weeks is required for a 26- to 27-pound tom, live weight (82 percent dressing). In a typical feed ration, corn and soybean meal are used in a ratio of 70/30 for broilers and turkeys.

The demand structure provides a representation of consumer behavior and does not presume that consumers instantaneously adjust to shifts in relative prices and income. The persistence in consumption patterns implies the axioms of consumer behavior may be violated in the short run. Thus, consumers may not behave in a manner predicted by theory because of habit formation and imperfect information flows. However, in the long run these impediments are presumed not to exist, and thus, the precepts of consumer behavior imposed by consumer demand theory on the long-run demand also constrain the behavior of consumers in the short run.

The broiler price is determined at the retail level. Supply is essentially perfectly inelastic and, thus, the level of price is dependent on demand. The price determination process of the broiler model is provided in Figure 2. The retail price is dependent on domestic broiler demand, prices of competing meat and food products, and food expenditures. The turkey price is determined at the wholesale price level (Figure 3). Wholesale price is estimated in place of farm price because of strong vertical integration in the turkey industry.

Review of Previous Econometric Models

Most econometric specifications of the livestock and poultry sectors remain tied to relatively simple supply structures that use distributed lags of input and output prices and lags reflecting biological time constraints inherent in the production process. Seasonality, an important feature of the livestock and poultry industries, is handled with seasonal dummy variables. The continuance of this basic supply structure in part reflects the constancy in the livestock and poultry production growth process, ease of its implementation and estimation, and the relative success in capturing producer behavior. Demand specifications are predominantly simple static linear structures that do not presuppose adherence to the axioms of consumer behavior.

In many livestock and poultry models, the demand components are estimated in the price-dependent form, with per capita meat quantities and income as the explanatory variables (e.g., Harlow 1962; Heien 1975, 1976, 1977). Fox (1953) suggested this specification, since in the short term the production is essentially fixed. Consequently, estimation could be made with ordinary least squares (OLS). However, this construction with a price-dependent demand form has not always been followed (Freebairn and Rausser 1975; Arzac and Wilkinson 1979).

The prevalent form of demand components used in livestock and poultry sector models is static and ad hoc in nature, not following the precepts of consumer behavior (Tomek and Robinson 1977). In part this reflects the rejection of the axioms of consumer behavior in most food demand studies at the market level (Christensen and Manser 1977; Deaton and Muellbauer 1980). The reasons for the rejection of the Slutsky conditions are many; they may be related in part to the assumption of consumers' instantaneous adjustment to changes in relative prices and income implied by the static approach.

Consumers very often react with some delay to changes in relative prices and income. Habit formation in consumption may lead to delayed responses and an adjustment process leading to a new equilibrium (Pollack and Wales 1980; Blanciforti et al. 1986; Heien 1982; Johnson et al. 1984). This innate inertia in consumption patterns implies that consumption dynamics should be explicitly introduced into the specification of the demand component.

Heien (1976) developed an econometric model of the U.S. poultry economy using annual data over the period 1950-1969. The model of the poultry sector contained three products: broilers, turkeys, and other chickens. Each of the three product sectors had an equation for retail demand, farm-level demand, production, and stock. Total supply for broilers was specified as a function of the wholesale broiler price, the feed cost, the wage rate for the broiler industry, an industry-capacity measure, and a time trend variable.

The retail price of broilers was estimated from a price-dependent demand equation specified as a function of the consumption of broilers and the normalized price (by per capita expenditure on nondurables and services) of competing products (beef, pork). All equations were estimated by OLS. The demand side of the model was found to be quite sensitive to income (income elasticity equal to 1.59) and substitute meat prices (with cross-price elasticities of 0.51 for pork and 0.18 for beef). The direct retail price elasticity for broilers was estimated to be -0.82.

The annual USDA broiler model, documented by Yanagida and Conway (1979), had its origin in the Heien (1976) model. The model included nine behavioral equations and three identities and was estimated over the period 1960-1976. In this model, chicken production was a function of eggs for hatching, the wholesale broiler price deflated by feed cost, and a trend factor. The supply elasticity associated with the deflated broiler price was 0.07. The deflated wholesale broiler price was linked to a deflated retail price index of frying chickens, a poultry processing industry wage rate, and a time trend variable. The retail price index of frying chickens deflated by personal consumption expenditures on nondurables was estimated as a function of beef, pork, and egg prices; the consumer price index of nondurables less food; young chicken disappearance per capita; and dummy variables. The estimation yielded a direct price flexibility of -1.11.

The annual USDA turkey model (Yanagida and Conway 1979) was also similar to the Heien model. Turkey production was estimated based on the farm price of turkeys, feed cost, an index of fuel costs, and a trend variable. An elasticity of 0.28 was associated with the lagged price/cost ratio in the turkey production equation. The total supply of turkey was identically equal to turkey production and beginning turkey stocks, and civilian consumption was endogenously determined.

Chavas (1978) developed quarterly models for the chicken, eggs, and turkey sectors. Eight equations were estimated for the broiler model, including placements, testing, hatching, production of meat, farm price, retail price, wholesale price, and stocks. Broiler demand was specified in a wholesale, price-dependent, mixed demand form as a function of civilian consumption, real disposable income, real wholesale price of turkeys, and retail price of beef and pork.

The characteristics of the supply components of the model were further detailed in Chavas and Johnson (1982), including dynamic production decisions about biological restrictions for broilers and turkeys. The technological lags defined the sequence of production stages for supply adjustments. Broiler placements were specified by a partial adjustment model. The supply structure included equations for the broiler testing, hatching, and production. The results indicated that broiler supply elasticities were higher at early stages of production, decreased with the production process, and approached zero in the last stages of production.

Chavas and Johnson (1982) used the characteristics of the turkey laying and hatching cycle to specify the shape of the lag structure of the explanatory variables. The turkey output price elasticity was 0.22 and the feed cost elasticity was -0.15. The price components of the turkey model included farm, wholesale, and retail price equations. The retail price was linked to the wholesale price and seasonal shifters. Similarly, the wholesale price equation was specified in price-dependent, mixed demand form. The turkey price elasticity of demand was -0.87.

Goodwin and Sheffrin (1982) estimated a simultaneous equation quarterly model of the broiler industry using maximum likelihood methods and explicitly tested the rational expectation hypothesis. They formulated the supply equation with the expected price and reported a demand price elasticity for broilers of -0.45, demand income elasticity of 1.217, supply expected-price elasticity of 0.99, and expected-feed cost elasticity of -0.69.

Estimation Results

Broiler Model

The estimated U.S. quarterly broiler model reported here contains six behavioral equations and two identities. These expressions provide behavioral representations of the major components of the industry's supply and demand structure.

The supply block of the broiler model includes four equations and one identity: placement, hatching, production, and other chicken production. A moving average of chicken placements is also included. In the price-consumption component of the broiler model, there are two equations (retail price and wholesale price) and one identity (consumption). Farm production, trade flows, shipments, and military use are considered exogenous.

The estimation was based on a sample consisting of 80 quarterly observations that covered the period 1967-1986. Single-equation estimation procedures were used in the supply block and in the wholesale price equation, using generalized least squares (GLS) as the estimation method. The retail demand equation was estimated within a system of demand equations that contained equations for beef, pork, and chicken per capita consumption. The estimation procedure used in the demand block was iterated seemingly unrelated regression (ITSUR). This procedure provides estimates that asymptotically approach the maximum likelihood estimates (Gallant 1987).

The estimation results presented in this section are accompanied by a description of the specification background of each equation. The description of the estimation results and underlying specification begin with results of the supply block. The chicken supply estimates are presented in Table 1; the estimates of the demand block and price determination components are presented in Table 2. The definitions of the variables are provided in Table 3.

Supply Component

Production begins with chicken placements (1) in the hatchery supply flock. The broiler chicks placed in the hatchery supply flock represent additions to the capital stock from which slaughter broilers are drawn. The nine-city wholesale broiler price (this price was replaced in 1983 by a 12-city price) and feed cost, both deflated by the consumer price index, are lagged two quarters and included as a proxy of anticipated returns to broiler production. Feed costs, which is the single most important cost item, is derived using a typical ration of 70/30 percent mix of corn to soybean meal.

The wholesale price has a positive effect on placement, and the feed costs a negative impact. A time trend variable indicates increasing placements of broilers over time due to gains in efficiency, resulting in lower prices to consumers and, in turn, increased broiler consumption.

Seasonal quarterly dummy variables are also included to account for seasonality in placements.

The number of chicks hatched (2) is primarily dependent on the size of the hatchery flock. A moving average of the chicken placements, lagged two quarters, gives an estimate of the flock size. The deflated wholesale broiler price and feed costs are lagged to allow for changes in expected profitability. Intertemporal changes are represented with a trend term, and seasonal variation is captured by quarterly dummy variables.

Broiler production (3) relates directly to the number of broilers hatched in the previous quarter. This lag structure reflects the time needed to bring chicks to market weight. The number of broilers raised is also a function of the profitability of broiler production. This is represented by the wholesale broiler price and feed cost, each lagged one quarter. A time trend variable is also included.

Other chicken production (4) includes all production other than broilers. As broiler production becomes less profitable, producers are more inclined to eliminate older and less productive chickens from their hatching flocks. The deflated wholesale chicken price (lagged one and two quarters) and the real interest rate (lagged one quarter) are included as explanatory variables. The one-quarter lagged price has a negative effect on other chicken production. The positive effect of the real interest rate illustrates that as it becomes more expensive to hold chickens in the hatchery flock, other chicken production will increase.

The moving average of chicken placements (5) indicates broiler egg production capability. The weights on the lagged broiler placements are derived from average laying cycle information (Chavas and Johnson 1982).

Demand Component

Price determination of the model is assumed to originate at the retail level. As Fox (1953) observed, livestock and poultry production is essentially fixed in the short run, and hence the determination of retail price depends on the location of the demand curve. Domestic disappearance, which determines per capita poultry consumption, is derived from the market closing identity. The estimation results of the demand components of the broiler model are provided in Table 2.

The retail demand component used in the broiler model incorporates persistence in consumption. The specification of the model identifies a general set of stochastic difference equations, obtaining their final form and applying error correction methods similar to the approach used by Anderson and Blundell (1983). A log-linear model is used, in spite of its theoretical limitations (LaFrance 1986), because it can be posited easily within the model's structure.

The general specification developed from the final form of the set of stochastic difference equations allows for persistence in consumption patterns and explicitly delineates both short- and long-run behavior. Dynamics in consumption enter through a fourth-order lag on the quantity consumed, Q_t, and in the other demand conditioning variables, X_t. The short-run behavior is captured in β_j, where j = 1,..., k conditioning variables, and the speed of the adjustment process is governed by $\alpha - 1$. The long-run parameters are ϵ_{ij}. The fourth-order lag structure was chosen because of the periodicity of the data. The fourth-order difference operator is Δ_4.

$$\Delta_4 \log Q_t = D + \sum_{j=1}^{k} B_j \Delta_4 \log X_{jt}$$

$$+ (\alpha - 1)[\log Q_{t-4} - \sum_{j=1}^{k} \epsilon_{ij} \log X_{t-4}] + e_t.$$

The terms within the brackets continually move consumption levels to their long-run equilibrium. If the adjustment parameter, $\alpha - 1$, is negative, and if long-run consumption, Q_{t-4}, is above the level implied by the conditioning variables, X_{t-4}, current consumption declines. This in essence is the error correction mechanism by which consumers adjust their consumption levels towards long-run equilibrium. Also, since the log-linear specification was used, the parameters β_j and ϵ_{ij} can be interpreted as the short- and long-run elasticities, respectively. Details on the development of this general specification can be found in Kesavan et al. (1989).

The general structure depicted above was used to estimate the <u>retail broiler demand</u> (6) within a system of demand equations that included representations for beef and pork, the primary competing meat products (Table 2). Turkey was not included in the demand model. The retail prices of beef and pork enter as conditioning variables in the broiler demand specification. Other conditioning variables included were per capita food expenditures and the consumer price index of food, a proxy for all competing food products. This set of conditioning variables implies a two-stage budgeting process (Brown and Heien 1972). Quarterly dummy variables were included to capture the seasonality in demand.

Habit formation in consumption levels, combined with a gradual adjustment process, implies that the axioms of consumer behavior need not apply to short-run behavior. At most, consumers would be aware of relative price changes in the short run. Thus, the homogeneity restriction was imposed on the short-run parameters. In the long run consumers have the ability to fully discern relative price and income shifts, and thus adhere to the precepts of consumer behavior. Hence, the homogeneity and symmetry restrictions were imposed on the long-run behavior. However, in the formulation of the model the restrictions imposed on the long-run behavior restrict the short-run parameters.[3] This forces a correspondence between short- and long-run behavior, and places restrictions on the dynamic behavior.

In general, the estimation results presented in Table 2 have the correct signs. However, the cross-price effects between chicken and beef are negative in the long run. This complementary relationship has been obtained in previous studies (Moschini and Meilke 1988). The negative elasticity with the price index of food suggests a complementary relationship with broiler consumption in the long run. The estimates suggest, as expected, the own- and cross-price effects increase as consumers have time to adjust to relative price changes. This behavior holds true for the expenditure elasticity as well.

The wholesale price of broilers (7) was explained by the deflated retail price of broilers and deflated marketing cost for poultry processors. This allows some flexibility in the marketing margin.

Per capita broiler consumption (8) includes exogenous supply and demand components: this identity was used to close the system equating per capita civilian consumption to total supply less military use, exports, and ending stocks. Military use and exports are considered exogenous.

Turkey Model

Given the importance of biological lags and vertically coordinated management in turkey production, successive stages of turkey production were analyzed as a single production process in the supply component of the turkey model. However, because of data limitations a simple supply structure is posited. The quarterly turkey model consists of two supply equations: hatching and production. The demand components provide the basis of the price determination. Price determination is at the wholesale level in the turkey model. The retail and farm-level prices for turkeys are determined from the wholesale price. Equations that determine ending turkey stocks and domestic disappearance are also included in the demand component. The estimation of the supply components of the turkey model is presented in Table 4. The demand component of the turkey model is presented in Table 5. The variables and their definitions are presented in Table 6.

Supply Component

The level of poults hatched is the fundamental basis for determining the level of turkey supply. Because of limited data availability, this model--unlike the one for broilers--does not include an equation for placements in the hatchery flocks. Turkey placement data were discontinued in September 1982 and were replaced by data on turkey poults hatched. As provided in Table 4, turkey poults hatched (1) is a function of turkeys hatched, lagged four quarters; the deflated wholesale price of turkeys, lagged one quarter; and feed costs, lagged one quarter. A time trend is included to account for intertemporal changes in the level of poults hatched, and seasonal dummy variables account for seasonality.

The specification presumes an adjustment cost in movements in the level of the hatchery supply flock, and thus the level of poults hatched. Adjustment costs are represented by a lagged dependent variable. Turkey producers also respond to their profitability expectations. Higher wholesale turkey prices lead to higher levels of poults hatched. Increases in feed costs reduce incentives to expand supply. A dummy variable (DM824) incorporates the changes in the data in September 1982, as discussed above.

Turkey production (2) is specified as a function of the turkey poults hatched, lagged one and two quarters. The lags are consistent with the production cycle, since it takes four to five months after hatching to produce a marketable turkey.

Turkey production is also dependent on output and input prices, as is turkey poults hatched. The deflated wholesale turkey price, lagged two quarters, is positively related to turkey production. Feed costs, lagged two quarters, are negatively related to turkey production. Both sets of prices are more inelastic in the turkey production equation than in that of poults hatched. These results correspond to Chavas and Johnson's (1982) assertion that producers have less discretion in later stages of the production process. Similar to the poults-hatched equation, the time trend is positively related to the dependent variable, and thus demonstrates the expansion in turkey production. Again, dummy variables measure the degree of seasonality in production, and a variable (DM824) accounts for changes in the data after September 1982.

Demand Component

The demand component determines the farm, wholesale, and retail prices. Also included in the demand component is a behavioral equation representing stockholding decisions, and an identity that determines turkey consumption. In the turkey model, price determination is at the wholesale level. In part, this reflects the degree of vertical coordination in the turkey sector.

The turkey wholesale price (3) is estimated as a function of total civilian turkey consumption, retail prices of other meat products, and per capita disposable income (Table 5) in real terms. Also included as explanatory variables are seasonal dummy variables. This specification is essentially a price-dependent demand equation.

The estimation results are as expected except for the sign of the coefficient on the pork retail price, RPPK. The results suggest that beef and chicken are substitutes, while pork is a complement. However, the coefficient on the retail price of pork, although negative, is statistically insignificant.

The turkey farm price (4) is directly dependent on the wholesale price of turkeys, both current and lagged one quarter. Similarly, the turkey retail price (5) is dependent on the wholesale price, wholesale price lagged one quarter, a time trend, and seasonal dummy variables.

The level of turkey ending stocks (6) is dependent on the level of beginning stocks, turkey production, and the percentage change in turkey wholesale prices. Also, a time trend and seasonal dummy variables are included. The trend and seasonal components of the equation explain most of the variability.

An identity determines turkey total disappearance (7). Turkey production and movements in stocks are the endogenous components of the identity. Exports, shipments, and military use are considered exogenous, and thus are not determined within the model's structure.

Validation and Evaluation

Model validation examines how well the behavior of the model corroborates the behavior of the modeled system. The estimated equations provide approximations of the supply and demand components within the broiler and turkey sectors. Thus, before these approximations can be used to evaluate the reaction of the broiler and turkey sectors to policy shifts and technological advances, the integrity of the system must be checked.

The ability of the model to track the historical behavior of the various supply and demand components was examined first. Historical simulation statistics, specifically the root-mean-percent square error (RMPSE), are presented for dynamic and static simulations. The implied elasticities of the model were compared with other econometric models of the broiler and turkey sectors using the elasticities derived with the nonlinear simulation techniques, following Fair (1980). Last, the forecast performance of the model was checked with an ex post forecast for the four quarters in 1987.

In Tables 7 and 8 the RMPSEs are presented for selected endogenous variables. This is a measure of the deviations of the predicted values from the historical values in percentage terms (Pindyck and Rubinfeld 1981). The dynamic simulations used predicted values of the endogenous variables in the lag structure. The static simulation used the actual values of the endogenous variables in the lag structure. Both simulations were conducted over the sample period.

The historical simulation statistics indicate that the models provided an adequate representation of the broiler and turkey sectors' behavior. However, the simulation statistics of the turkey ending stocks equation were larger than desired. Indeed, the simple specification used in the closing stocks equation may not be an adequate representation of this minor and highly seasonal demand component.

With linear models the dynamic properties can be examined through the reduced form equations of the estimated model. Mean paths, multipliers, and elasticities can be obtained directly from the reduced form equations.

However, with nonlinear models such as the broiler model, the reduced form expressions cannot be analytically derived. Also, closed form expressions of impact and dynamic multipliers are not generally known.

Fair (1980) illustrates simulation methods to derive the dynamic behavior of nonlinear models. In deriving the broiler model's dynamic behavior, these simulation techniques were applied with two simplifying assumptions. First, all stochastic terms were set to zero; second, the parameters were assumed to be known with certainty.

Briefly, the steps used to derive the approximate dynamic multipliers are as follows. First, a baseline solution was obtained. The baseline solution was obtained by setting all exogenous variables to their mean values (1984-1986 averages). The model was simulated until the endogenous variables reached constant levels. This baseline of steady-state solutions was then used for comparison of simulations in which selected exogenous variables were perturbed. The level of feed costs and retail beef and pork prices were increased by 10 percent from their initial mean values. The model was simulated again for each of these three exogenous shocks and was allowed to converge on a new steady-state solution. The new solution typically was obtained after 20 quarters. Percentage changes from the baseline for feed cost, retail beef price, and retail pork price are provided in Tables 9 through 11, respectively.

The responses of the selected endogenous variables indicate that the supply response was very inelastic in the short run, and they increased as the effects of movements in the chickens hatched and chickens placed permeated through the system. The underlying biological constraints on production prohibit instantaneous increases in supply without an underlying buildup of the supply breeding flocks. Thus, the full extent of supply response does not become appreciably apparent until after the first year of the sustained shock.

Note that in Table 9 the sustained 10 percent increase in feed cost leads to a very small increase in wholesale price and a very small reduction in total chicken production after the model equilibrates. Also, the sustained 10 percent increase in the retail beef price leads to a reduction in chicken supply and prices (Table 10). This unexpected result reflects the negative cross-price elasticity between beef and chicken in the long run. Of course, these multipliers were simulated holding all other variables constant; thus, dynamic cross-commodity effects are ignored. The sustained 10 percent increase in the retail pork price leads to a small increase in chicken production and to a 2.98 percent increase in the wholesale price (Table 11).

The total supply elasticities of broiler and turkey sector models were estimated at 0.10 for broilers and 0.23 for turkeys. These reported supply elasticities for the CARD quarterly poultry models are the response to a one-year increase in the wholesale chicken price or wholesale turkey price. The estimated supply elasticities for the CARD model are quite similar to those of previous works. The comparisons of broiler supply elasticities are presented in Table 12. Turkey model supply elasticities are provided in Table 13.

Previous studies have reported higher supply elasticities when estimated with a single supply response equation. For example, in an annual broiler model Heien (1976) obtained a supply elasticity of 0.36. Similarly, Goodwin and Sheffrin (1982) obtained a broiler supply elasticity of 0.988 in a rational expectations model. Earlier, Cromarty (1959) obtained a total poultry supply elasticity of 0.678 in an annual model.

Estimates of poultry supply elasticities are limited. Many previous studies have either failed to report supply elasticity estimates or have obtained a statistically insignificant relationship between poultry prices and production (e.g., Freebairn and Rausser 1975). The dominance of productivity or trend terms in explaining movements in poultry production, in part, renders this latter result. Nevertheless, the structural equation elasticities in the CARD poultry models can be compared equation by equation with some previous results.

In the CARD chicken model the supply elasticity for the wholesale broiler price in the placement equation was 0.17. In their placement equations, Chavas (1978) and Chavas and Johnson (1982) obtained more responsive elasticities for the wholesale price of broilers at 0.98 and 0.601, respectively. More similar elasticity results were obtained in the broiler hatched equations. In the CARD chicken model, the supply elasticity with respect to the wholesale broiler price in the hatch equation was 0.14. Chavas (1978) and Chavas and Johnson (1982) provided slightly less inelastic estimates of 0.29 and 0.192 in their respective broiler hatched equations. The elasticity estimates with respect to the wholesale price of broilers in the broiler production equation were even more similar (see Table 12).

The total supply elasticity of the CARD turkey model was somewhat lower than those estimates obtained from single-equation turkey supply models. However, structural equation elasticities were quite similar. In the CARD turkey model the elasticity with respect to the wholesale turkey price in the turkey hatch equation was 0.24 (Table 13). Chavas (1978) and Chavas and Johnson (1982) obtained nearly identical estimates. The elasticity in the CARD turkey model's production equation with respect to the turkey wholesale price was 0.14. This is slightly lower than previous results (Chavas 1978; Yanagida and Conway 1979; Chavas and Johnson 1982).

Differences among the elasticities estimates may exist for many reasons. The period of study is one reason. Differences in the calculation of the elasticities may also affect their value. Analytical approaches that obtain elasticity estimates directly may provide a different measure of supply response compared with the simulation approach used in this study.

The demand elasticities for the complete livestock demand system are presented in Table 14. In general, the demand elasticities become more elastic in the long run. This is intuitively appealing since consumers can fully adjust to relative price and income changes as time passes. In general, the chicken demand elasticities have the anticipated signs in the long run. However, the long-run, cross-price elasticity with beef is negative, which suggests a complementary relationship. The cross-price elasticity with pork is positive in both the short run and the long run, and the own-price elasticity is negative and more elastic in the long run. Table 15 gives demand elasticities from selected demand studies. The demand elasticities in the CARD model are in line with previous results.

Ex post forecasts were made for the four quarters of 1987. The RMPSEs for the forecasts are provided for selected endogenous variables in Tables 16 and 17. The results were acceptable for the chicken model, but somewhat disappointing in the turkey model. These results were not entirely surprising. The forecast statistics of the turkey ending stocks and turkey wholesale and farm price were larger than desired. The simple specification of turkey ending stocks may not be an adequate representation due to a highly seasonal demand component. Nevertheless the poultry models do project adequately for the total supply and price movements, particularly for broilers.

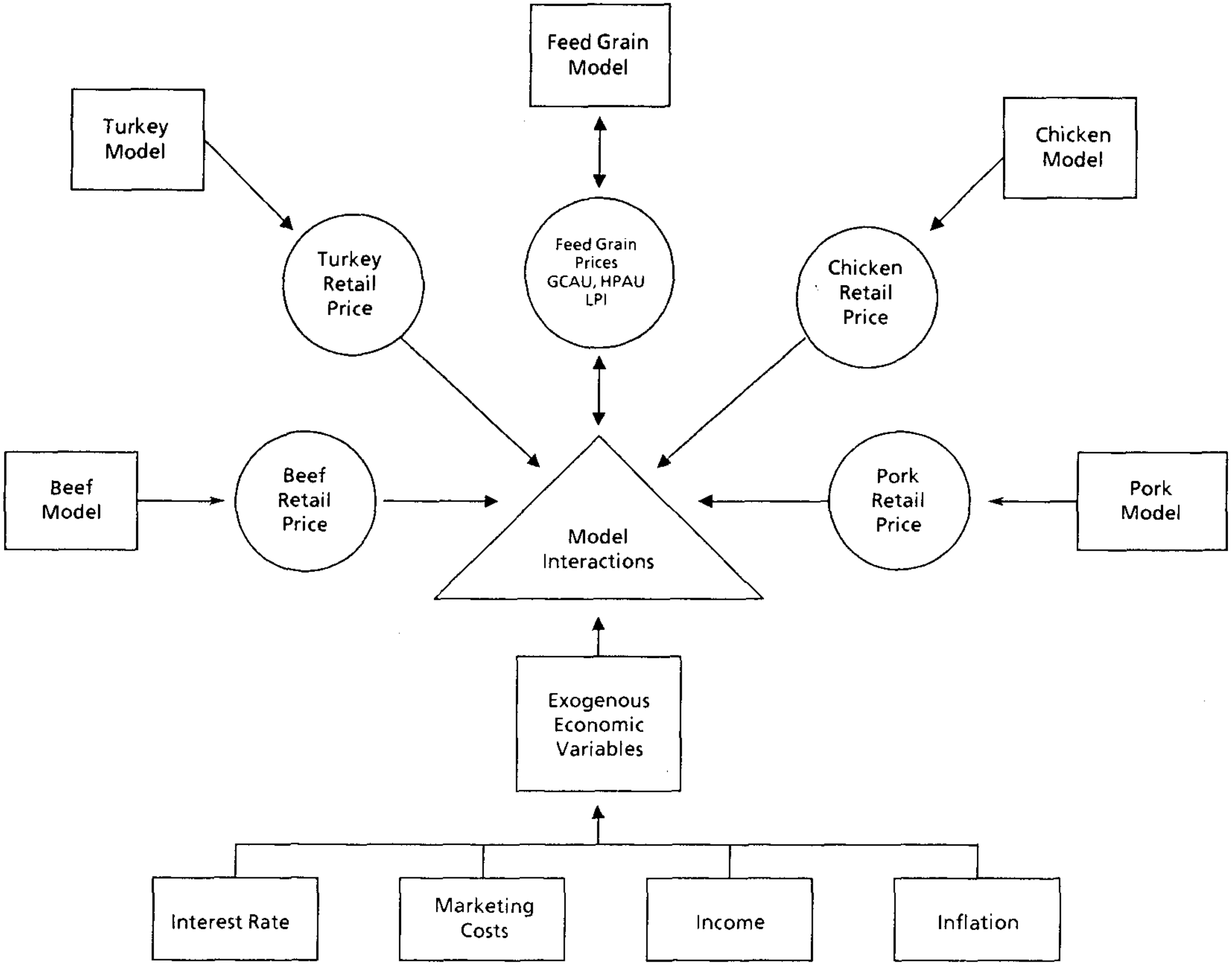

Figure 1. Livestock sector model linkages.

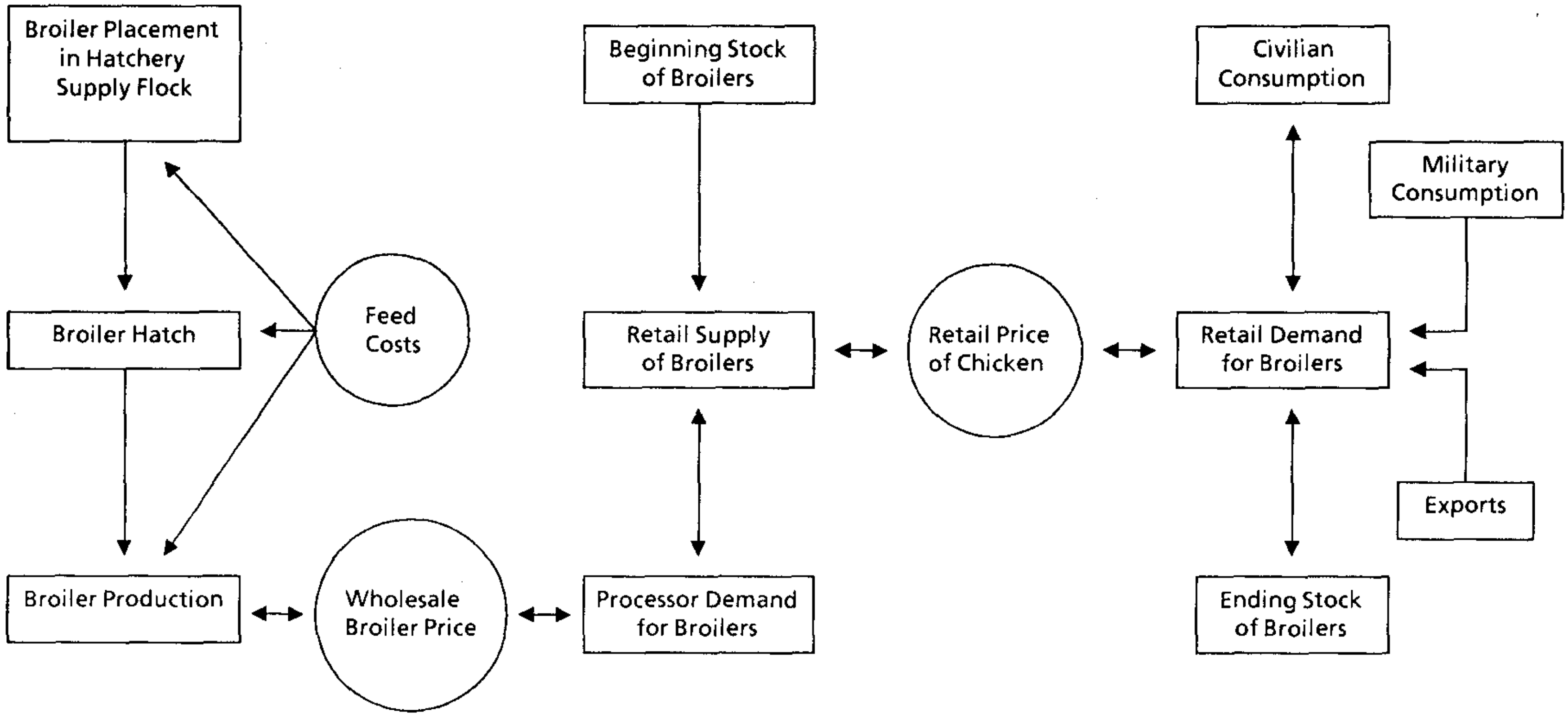

Figure 2. Broiler sector relationship.

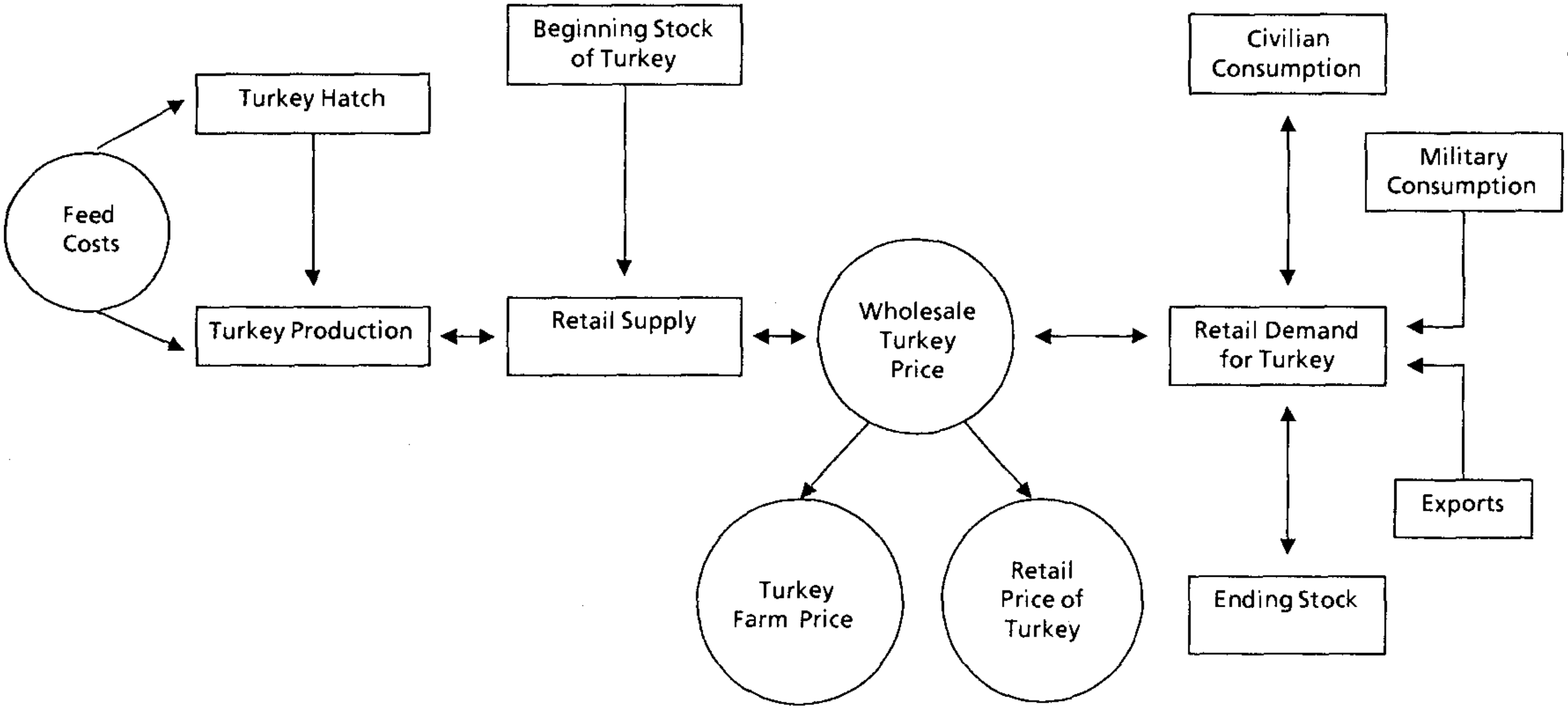

Figure 3. Turkey sector relationship.

Table 1. Estimates of chicken supply components

(1) Chicken placements (GLS)

$$CPLACE_t = 0.46\ CPLACE_{t-4} + 7.24(WPCK/CPI)_{t-2}$$
(3.98)[a] (1.61)
[0.45][b] [0.17]

$$-54.45(FC/CPI)_{t-2} + 0.10\ T65 + 3.54\ D1$$
(-2.61) (3.25) (2.11)
[-0.16]

$$+ 4.03\ D2 + 3.39\ D3 + 3.59\ D4$$
(2.38) (2.09) (2.18)

S/M = 0.068[c]

$$u_t = -0.4195\ u_{t-1} + \epsilon_t$$
(-3.78)

(2) Chicks hatched (GLS)

$$CHATCH_t = 17.20\ BRPL_{t-2} + 589.64(WPCK/CPI)_{t-1}$$
(7.11) (4.24)
[0.40] [0.14]

$$- 2079.89(FC/CPI)_{t-1} + 29.21\ T65 + 119.54\ D1$$
(-2.27) (25.91) (1.73)
[-0.06]

$$+ 177.56\ D2 + 95.11\ D3 + 41.48\ D4$$
(2.55) (1.38) (0.58)

S/M = 0.021

$$u_t = -0.5641\ u_{t-1} + \epsilon_t$$
(-5.59)

(3) Broiler production (GLS)

$$CPROD_t = 1.92\ CHATCH_{t-1} + 795.42(WPCK/CPI)_{t-1}$$
(9.02) (2.36)
[0.73] [0.07]

$$- 3559.64(FC/CPI)_{t-1} + 56.92\ T65 - 126.74\ D1$$
(-2.17) (9.14) (-0.83)
[-0.04]

$$- 61.52\ D2 - 213.89\ D3 - 222.74\ D4$$
(-0.37) (-1.20) (-1.36)

S/M = 0.020

$$u_t = -0.3706\ u_{t-1} + \epsilon_t$$
(-3.26)

Table 1. Estimates of chicken supply components (continued)

(4) Other chicken production (GLS)

$$OCPROD_t = \underset{\substack{(5.43)\\ [0.08]}}{2.91}\, RIFCL_{t-1} - \underset{\substack{(-1.14)\\ [-0.11]}}{1.88}(WPCK/FC)_{t-1}$$

$$- \underset{\substack{(-1.75)\\ [-0.19]}}{3.33}(WPCK/FC)_{t-2} + \underset{(11.44)}{182.15}\, D1 + \underset{(11.37)}{177.69}\, D2$$

$$+ \underset{(10.47)}{165.05}\, D3 + \underset{(10.75)}{171.08}\, D4$$

S/M = 0.085

$$u_t = \underset{(-5.81)}{-0.5763}\, u_{t-1} + \epsilon_t$$

(5) Moving average of chicken placement

$$BRPL_t = CPLACE_t + 0.8\ CPLACE_{t-1} + 0.61\ CPLACE_{t-2}$$

[a]Asymptotic t-statistics are in parentheses.

[b]Elasticities evaluated at sample means are in brackets.

[c]S/M equals the standard error divided by sample mean of the dependent variable.

Table 2. Estimates of chicken demand components

(6) Retail broiler demand (ITSUR)[a,b]

$$\begin{aligned}
LOG(PCCK4_t) = &\underset{(-6.76)^c}{-2.7011} - \underset{(-0.21)}{0.004}\ D2 - \underset{(-0.22)}{0.006}\ D3 - \underset{(-4.52)}{0.1244}\ D4 \\
&+ 0.17\ LOG(PCCK4_{t-4}) + \underset{(0.71)}{0.058}[LOG(RPBF4_t) - LOG(RPBF4_{t-4})] \\
&+ \underset{(3.45)}{0.1942}[LOG(RPPK_t) - LOG(RPPK_{t-4})] \\
&- \underset{(-10.65)}{0.6292}[LOG(RPCK_t) - LOG(RPCK_{t-4})] \\
&+ 0.3775[LOG(CPIFOOD_t) - LOG(CPIFOOD_{t-4})] \\
&+ \underset{(0.01)}{0.0004}[LOG(FEXP_t) - LOG(FEXP_{t-4})] \\
&+ (0.17 - 1)^d\ [LOG(PCCK4_{t-4}) + 0.174\ LOG(RPBF4_{t-4}) \\
&- \underset{(4.66)}{0.3370}\ LOG(RPPK_{t-4}) + \underset{(-17.08)}{1.050}\ LOG(RPCK_{t-4}) \\
&- 0.3563\ LOG(CPIFOOD_{t-4}) - \underset{(4.54)}{1.2387}\ LOG(FEXP_{t-4})]
\end{aligned}$$

$S/M = 0.0016^e$

(7) Real wholesale price of broilers (GLS)

$$WPCK_t/CPI_t = \underset{\substack{(47.83)\\ [1.07]}}{0.73}(RPCK/CPI)_t - \underset{\substack{(-3.39)\\ [-0.02]}}{0.01}(MKTCOST/CPI)_t$$

$S/M = 0.038$

$$u_t = \underset{(-3.34)}{-0.4321}\ u_{t-1} + \epsilon_t$$

Table 2. Estimates of chicken demand components (continued)

(8) Per capita broiler consumption

$$PCCK4_t = (CPROD_t + CENDSTK_{t-1} - CENDSTK_t - CEXPTS_t - CSHPMTS_t - CMILUSE_t)/POPN4_t$$

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

[b]The retail broiler demand was inverted to obtain the logarithm of the retail price of broilers in simulations.

[c]Asymptotic t-statistics are in parentheses. Elasticities in the retail demand equation are the coefficients; elsewhere elasticities, evaluated at sample means, appear in brackets.

[d]The adjustment coefficients were restricted.

[e]S/M equals the standard error divided by the sample mean of the dependent variable.

Table 3. U.S. quarterly chicken model variables and their sources

Variables	Units	Labels	Source
Chicken, broiler-type, placements	millions	CPLACE	USDA, Livestock and Poultry
Chicken, broiler-type, hatched	millions	CHATCH	USDA, Livestock and Poultry
Chicken, broiler production	million pounds	CPROD	USDA, Livestock and Poultry
Moving average of chick placement		BRPL	CPLACE + 0.8 $CPLACE_{t-1}$ + 0.61 $CPLACE_{t-2}$
Other chicken production	million pounds	OCPROD	USDA, Livestock and Poultry
Chicken, broiler, 12-city average	dollars/ pound	WPCK	USDA, Livestock and Poultry
Retail price of chicken	dollars/ pound	RPCK	USDA, Livestock and Poultry
Per capita civilian broiler consumption	pounds	PCCK4	USDA, Livestock and Poultry
Feed costs		FC	1.25 PC04 + 0.015 PSOYB
Corn price	dollars/ bushel	PC04	USDA, Agricultural Prices
Soymeal price, Decatur	dollars/ton	PSOYB	USDA, Feed
Consumer price index	1967 = 100	CPI	U.S. Department of Commerce, Survey of Current Business
Consumer price index--food	1967 = 100	CPIFOOD	USDA, Agricultural Outlook
Food consumption expenditures (not seasonally adjusted)	billion dollars	FOODEXP	Personal correspondence, U.S. Department of Commerce

Table 3. U.S. quarterly chicken model variables (continued)

Variables	Units	Labels	Source
Per capita personal consumption expenditures--food	dollars/person	FEXP	$\frac{FOODEXP * 1000}{POPN4}$
Index of meat packers hourly earnings	1967 = 100	IMPHRE	U.S. Department of Commerce, _Employment and Earnings_
Producer price index of fuels and power	1967 = 100	PPIFP	U.S. Department of Commerce, _Survey of Current Business_
Marketing cost		MKTCOST	$\frac{0.5(PPIFP+IMPHRE)}{CPI}$
U.S. population	millions	POPN4	U.S. Department of Commerce, _Survey of Current Business_
Interest rate on feeder cattle loans	percent	IFCL	Federal Reserve Bank, _Agricultural Letter_
Real interest rate on feeder cattle loans	percent	RIFCL	IFCL - INFL
Inflation rate	percent	INFL	$100\{EXP[4 * LOG(CPI_t/CPI_{t-1})] - 1\}$
Retail price of beef	dollars/ pound	RPBF4	USDA, _Livestock and Poultry_
Retail price of pork	dollars/ pound	RPPK	USDA, _Livestock and Poultry_
Broiler ending stocks	million pounds	CENDSTK	USDA, _Livestock and Poultry_
Broiler exports	million pounds	CEXPTS	USDA, _Livestock and Poultry_
Broiler shipments	million pounds	CSHPMTS	USDA, _Livestock and Poultry_
Broiler military purchases	million pounds	CMILUSE	USDA, _Livestock and Poultry_
Seasonal dummy variables		D1, D2, D3, D4	
Trend variable	1965 = 1	T65	

Table 4. Estimates of turkey supply components

(1) Turkey poults hatched (GLS)

$$THATCH_t = \underset{\substack{(13.76)^a \\ [0.766]^b}}{0.7889}\, THATCH_{t-4} + \underset{\substack{(4.42) \\ [0.24]}}{31.6599}(TWHP/CPI)_{t-1}$$

$$- \underset{\substack{(-4.57) \\ [-0.20]}}{1.6170}\, FC_{t-1} + \underset{(7.22)}{1.2126}\, T65 - \underset{(-2.13)}{7.8216}\, D1$$

$$- \underset{(-0.89)}{3.6347}\, D2 - \underset{(-2.81)}{8.5764}\, D3 - \underset{(-3.55)}{10.7583}\, D4$$

$$- \underset{(-2.17)}{2.9032}\, DM824$$

$S/M = 0.056^c$ $\qquad$ $u_t = \underset{(-2.50)}{-0.294}\, u_{t-1} + \epsilon_t$

(2) Turkey production (GLS)

$$TPROD_t = \underset{\substack{(2.37) \\ [0.14]}}{1.8668}\, THATCH_{t-1} + \underset{\substack{(14.77) \\ [0.90]}}{12.0868}\, THATCH_{t-2}$$

$$+ \underset{\substack{(2.44) \\ [0.12]}}{199.0982}(TWHP/CPI)_{t-2} - \underset{\substack{(-2.04) \\ [-0.08]}}{8.4120}\, FC_{t-2}$$

$$+ \underset{(2.59)}{4.1008}\, T65 - \underset{(-6.18)}{207.0836}\, D1 - \underset{(-0.84)}{32.0402}\, D2$$

$$- \underset{(-0.62)}{29.4801}\, D3 - \underset{(-3.64)}{166.9125}\, D4 + \underset{(5.08)}{74.2100}\, DM824$$

$S/M = 0.052$ $\qquad$ $u_t = \underset{(-1.28)}{-0.157}\, u_{t-1} + \epsilon_t$

[a] Asymptotic t-statistics are in parentheses.

[b] Elasticities evaluated at sample mean are in brackets.

[c] S/M equals the standard error divided by the sample mean of the dependent variable.

Table 5. Estimates of turkey demand components

(3) Turkey wholesale price (GLS)

$$TWHP_t/CPI_t = \underset{\substack{(-4.66)^{a}\\ [-0.54]^{b}}}{-\,0.000266}\; TCSUMP_t + \underset{\substack{(6.32)\\ [0.89]}}{0.7647}(RPCK/CPI)_t$$

$$+ \underset{\substack{(1.90)\\ [0.29]}}{0.0955}(RPBF4/CPI)_t - \underset{\substack{(-0.21)\\ [-0.03]}}{0.01296}(RPPK/CPI)_t$$

$$+ \underset{\substack{(4.52)\\ [1.32]}}{0.01138}(NPCDY/CPI)_t$$

$$- \underset{(-3.44)}{0.3173}\; D1 - \underset{(-3.29)}{0.3026}\; D2$$

$$- \underset{(-2.84)}{0.2565}\; D3 - \underset{(-1.28)}{0.1157}\; D4$$

S/M = 0.077[c]

$$u_t = \underset{(-2.53)}{-0.297}\; u_{t-1} + \epsilon_t$$

(4) Turkey farm price (GLS)

$$TFMP_t/CPI_t = \underset{\substack{(15.69)\\ [0.85]}}{0.5006}\; TWHP_t + \underset{\substack{(1.70)\\ [0.09]}}{0.0541}(TWHP/CPI)_{t-1}$$

$$+ \underset{(1.04)}{0.0066}\; D1 + \underset{(1.24)}{0.0072}\; D2$$

$$+ \underset{(1.65)}{0.0100}\; D3 + \underset{(2.69)}{0.0171}\; D4$$

S/M = 0.048

$$u_t = \underset{(-3.17)}{-0.357}\; u_{t-1} + \epsilon_t$$

Table 5. Estimates of turkey demand components (continued)

(5) Turkey retail price (GLS)

$$TRTP_t/CPI_t = \underset{\substack{(4.34)\\ [0.21]}}{0.2764}\ TWHP_t + \underset{\substack{(7.03)\\ [0.33]}}{0.4408}(TWHP/CPI)_{t-1}$$

$$- \underset{(-3.99)}{0.0038}\ T65 + \underset{(7.17)}{0.2326}\ D1$$

$$+ \underset{(7.79)}{0.2433}\ D2 + \underset{(7.65)}{0.2444}\ D3$$

$$+ \underset{(6.78)}{0.2246}\ D4$$

S/M = 0.039 $\qquad u_t = \underset{(-4.67)}{-0.493}\ u_{t-1} + \epsilon_t$

(6) Turkey ending stocks (GLS)

$$TENDSTK_t = \underset{\substack{(7.48)\\ [0.60]}}{0.6024}\ TENDSTK_{t-1} + \underset{\substack{(7.79)\\ [1.30]}}{0.6280}\ TPROD_t$$

$$- \underset{\substack{(-0.20)\\ [0.0001]}}{28.7768}\ PRCHANGE_t - \underset{(-6.36)}{12.8924}\ T65 + \underset{(1.57)}{34.2936}\ D1$$

$$+ \underset{(0.84)}{19.4683}\ D2 + \underset{(0.66)}{29.0559}\ D3 + \underset{(-5.68)}{-320.0620}\ D4$$

S/M = 0.148 $\qquad u_t = \underset{(-1.19)}{-0.1437}\ u_{t-1} + \epsilon_t$

(7) Turkey total disappearance

$$TCSUMP_t = TPROD_t + TENDSTK_{t-1} - TENDSTK_t - TEXPSHP_t - TMILUSE_t$$

[a]Asymptotic t-statistics are in parentheses.

[b]Elasticities evaluated at sample mean are in brackets.

[c]S/M equals the standard error divided by the sample mean of the dependent variable.

Table 6. U.S. quarterly turkey model variables and their sources

Variables	Units	Labels	Source[a]
Turkey hatched	millions	THATCH	USDA, *Livestock and Poultry*
Turkey production	million pounds	TPROD	USDA, *Livestock and Poultry*
Turkey ending stocks	million pounds	TENDSTK	USDA, *Livestock and Poultry*
Turkey farm price, live weight	cents/ pound	TFMP	USDA, *Livestock and Poultry*
Turkey wholesale price, hens, 8-16 pounds	cents/ pound	TWHP	USDA, *Livestock and Poultry*
Turkey, 4-region average retail price	cents/ pound	TRTP	USDA, *Livestock and Poultry*
Turkey, total civilian disappearance	million pounds	TCSUMP	USDA, *Livestock and Poultry*
Chicken, retail price	dollars/ pound	RPCK	USDA, *Livestock and Poultry*
Feed costs		FC	1.25 PCO4 + 0.015 PSOYB
Corn price	dollars/ bushel	PCO4	USDA, *Agricultural Prices*
Soymeal price, Decatur	dollars/ ton	PSOYB	USDA, *Feed*
Consumer price index	(1967 = 100)	CPI	U.S. Department of Commerce, *Survey of Current Business*
Per capita disposable income	dollars/ person	NPCDY	U.S. Department of Commerce, *Survey of Current Business*
U.S. population	millions	POPN4	U.S. Department of Commerce, *Survey of Current Business*

Table 6. U.S. Quarterly Turkey Model Variables (continued)

Variables	Units	Labels	Source
Retail price of beef	dollars/ pound	RPBF4	USDA, *Livestock and Poultry*
Retail price of pork	dollars/ pound	RPPK	USDA, *Livestock and Poultry*
Turkey exports and shipments	million pounds	TEXPSHP	USDA, *Livestock and Poultry*
Turkey military purchases	million pounds	TMILUSE	USDA, *Livestock and Poultry*
Seasonal dummy variables		D1, D2, D3, D4	
Time variable	1965 = 1	T65	
DM824	Dummy variable (new series of turkey poults placed started in September 1982 replaced in turkey hatched) 0; before 1982 fourth quarter, use turkey hatched as THATCH 1; after 1982 fourth quarter, use turkey poults placed as THATCH		
Wholesale turkey price change		PRCHANGE	$(TWHP/CPI)_t$ - $(TWHP/CPI)_{t-1}$

[a]See References for further information on data sources.

Table 7. Historical simulation statistics for chicken model

Variable	Label	Dynamic RMPSE[a]	Static RMPSE
Chicken, broiler-type, placements	CPLACE	8.89	7.61
Chicken, broiler-type, hatched	CHATCH	3.74	2.72
Chicken, broiler production	CPROD	3.94	2.54
Chicken, other chicken production	OCPROD	11.18	11.02
Moving average of chicken placement	BRPL	7.78	3.17
Chicken, per capita consumption	PCCK4	4.22	3.94
Chicken, retail price of broilers	RPCK	6.74	8.91
Chicken, wholesale price of broilers	WPCK	9.96	11.38

NOTE: Historical simulation was made over the sample period, 1967.00-1986.75.

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

Table 8. Historical simulation statistics for turkey model

Variable	Label	Dynamic RMPSE[a]	Static RMPSE
Turkey, total poults hatched	THATCH	10.10	6.71
Turkey, total production	TPROD	12.51	8.79
Turkey, ending stock of frozen turkeys	TENDSTK	34.19	18.48
Turkey, farm price	TFMP	8.66	7.61
Turkey, wholesale price	TWHP	8.31	7.69
Turkey, retail price	TRTP	5.21	4.64
Turkey, total civilian disappearance	TCSUMP	9.39	10.22

NOTE: Historical simulation was made over the sample period, 1967.00-1986.75.

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

Table 9. Selected broiler model variable responses to a 10 percent increase in feed cost

Period	CHATCH	CPLACE	CPROD	OCPROD	WPCK	RPCK
			(Percentage Change)			
1	0.00	0.00	0.00	0.00	0.00	0.00
2	-0.29	0.00	-0.18	1.05	0.33	0.30
3	-0.27	-0.87	-0.37	2.88	0.67	0.61
4	-0.24	-0.84	-0.34	2.79	0.62	0.56
5	-0.38	-0.80	-0.32	2.73	0.59	0.53
6	-0.48	-0.80	-0.41	2.74	0.58	0.53
7	-0.55	-1.21	-0.48	2.75	0.52	0.47
8	-0.55	-1.19	-0.53	2.76	0.64	0.58
9	-0.60	-1.18	-0.53	2.75	0.65	0.59
10	-0.65	-1.17	-0.56	2.73	0.68	0.62
15	-0.73	-1.41	-0.64	2.71	0.71	0.64
20	-0.75	-1.43	-0.66	2.70	0.74	0.67

NOTE: Values represent approximate total elasticities with respect to feed costs. The elasticities allow for demand and supply adjustments within the broiler sector but exclude cross-commodity adjustments. The values were generated through dynamic simulation at the 1984-1986 mean values of the exogenous variables.

Table 10. Selected broiler model variable responses to a 10 percent increase in the retail price of beef

Period	CHATCH	CPLACE	CPROD	OCPROD	WPCK	RPCK
			(Percentage Change)			
1	0.00	0.00	0.00	0.00	0.95	0.86
2	0.07	0.00	0.04	-0.11	0.88	0.80
3	0.07	0.10	0.08	-0.29	0.79	0.72
4	0.06	0.10	0.08	-0.27	0.81	0.73
5	0.08	0.09	0.07	-0.25	-2.85	-2.58
6	-0.20	0.09	-0.05	0.16	-2.59	-2.34
7	-0.17	-0.26	-0.23	0.88	-2.22	-2.01
8	-0.14	-0.24	-0.20	0.78	-2.28	-2.07
9	-0.20	-0.20	-0.18	0.72	-0.92	-0.83
10	-0.13	-0.21	-0.17	0.57	-1.08	-0.98
15	-0.21	-0.29	-0.21	0.55	-1.51	-1.37
20	-0.22	-0.29	-0.20	0.46	-1.46	-1.32

NOTE: Values represent approximate total elasticities with respect to the retail price of beef. The elasticities allow for demand and supply adjustments within the broiler sector but exclude cross-commodity adjustments. The values were generated through dynamic simulation at the 1984-1986 mean values of the exogenous variables.

Table 11. Selected broiler model variable responses to a 10 percent increase in the retail price of pork

Period	CHATCH	CPLACE	CPROD	OCPROD	WPCK	RPCK
			(Percentage Change)			
1	0.00	0.00	0.00	0.00	3.32	3.01
2	0.26	0.00	0.12	-0.38	3.08	2.79
3	0.24	0.36	0.29	-1.03	2.77	2.51
4	0.22	0.34	0.27	-0.95	2.81	2.55
5	0.27	0.30	0.25	-0.89	3.03	2.74
6	0.33	0.31	0.30	-0.92	3.07	2.78
7	0.36	0.50	0.34	-0.97	3.17	2.87
8	0.36	0.49	0.36	-0.99	3.10	2.81
9	0.38	0.48	0.36	-1.00	3.01	2.73
10	0.40	0.48	0.37	-0.98	2.99	2.71
15	0.44	0.58	0.41	-0.96	3.01	2.72
20	0.44	0.59	0.41	-0.95	2.98	2.70

NOTE: Values represent approximate total elasticities with respect to the retail price of pork. The elasticities allow for demand and supply adjustments within the broiler sector but exclude cross-commodity adjustments. The values were generated through dynamic simulation at the 1984-1986 mean values of the exogenous variables.

Table 12. Comparison of selected chicken supply response elasticities

Study	Data	Period	Supply Elasticities
Fisher (1958)	annual	1925-1941	-0.18 to 0.31[a] 0.26[b]
Hayami (1960)	monthly	1955-1959	-0.168[a,c] 0.267[b]
Heien (1976)	annual	1950-1969	0.36
Chavas (1978)	quarterly	1965-1976	0.98 (placement equation) 0.29 (hatching equation) 0.09 (production equation)
Yanagida and Conway (1979)	annual	1960-1976	0.07 (production equation)
Chavas and Johnson (1982)	quarterly	1965-1976	0.601 (placement equation) 0.023 (testing equation) 0.192 (hatching equation) 0.064 (production equation)
Goodwin and Sheffrin (1982)	quarterly	1968-1977	0.988[d]
CARD (1989)	quarterly	1967-1986	0.17 (placement equation) 0.14 (hatching equation) 0.07 (production equation) 0.10[a]

[a]Short-run elasticity.

[b]Long-run elasticity.

[c]Not statistically significant.

[d]Supply elasticity with respect to expected wholesale price.

Table 13. Comparison of selected turkey supply response elasticities

Study	Data	Period	Supply Elasticities
Hayami (1960)	monthly	1955-1959	0.346[a] 0.785[b]
Soliman (1967)	quarterly	1955-1964[a]	0.459[b] 0.539[b]
Heien (1976)	annual	1950-1969	0.56
Chavas (1978)	quarterly	1965-1976	0.83 (testing equation) 0.25 (hatching equation) 0.22 (production equation)
Yanagida and Conway (1979)	annual	1960-1976	0.28 (production equation)
Chavas and Johnson (1982)	quarterly	1965-1976	0.80 (testing equation) 0.23 (hatching equation) 0.21 (production equation)
CARD (1989)	quarterly	1967-1986	0.24 (hatching equation) 0.14 (production equation) 0.23[a]

[a]Short-run elasticity.

[b]Long-run elasticity.

Table 14. Estimated parameters for general dynamic model with homogeneity and symmetry imposed in the long run and homogeneity imposed in the short run (estimation period 1967-1986)

		Beef	Pork	Chicken	Expenditure	Lag adj.
Beef	SR	-0.52 (0.08)	0.23 (0.05)	-0.14 (0.05)	0.43 (0.20)[a]	0.33
	LR	-0.80 (0.07)	0.30 (0.06)	-0.028 (0.02)	1.06 (0.30)	
Pork	SR	0.42 (0.06)	-0.70 (0.05)	-0.06 (0.04)	0.19 (0.17)	0.25
	LR	0.62	-0.60 (0.07)	0.13 (0.07)	0.68 (0.23)	
Chicken	SR	0.06 (0.08)	0.19 (0.06)	-0.63 (0.06)	0.0004 (0.23)	0.17
	LR	-0.17	0.34	-1.05 (0.06)	1.24 (0.27)	

[a]Figures within parentheses indicate the standard error.

Table 15. Summary of estimated elasticities by different studies

Study	Data	Period	Demand Specifications	Own-price[a]	Elasticities Income/ Expenditure	Cross-price[b]	
George and King (1971)	Time series and cross-section	1946-1971 1965	Ad hoc	Beef -0.64 Pork -0.41 Chik -0.78	0.29 0.13 0.18	BP 0.08 PB 0.08 CB 0.20	BC 0.07 PC 0.04 CP 0.12
Christensen and Manser (1977)	Annual	1947-1971	Translog	Beef -0.96 Pork -0.76 Plty -0.98	1.33 0.78 0.78	BP -0.16 PB -0.08 CB -0.03	BC -0.07 PC 0.10 CP 0.21
Pope et al. (1980)	Annual	1950-1975	Ad hoc state adjustment model with Box-Cox transformation	Beef -0.68 Pork -0.81 Plty -0.61	0.61 0.38 0.58	BP 0.06 PB 0.32 CB 0.29	BC -0.01 PC 0.19 CP 0.24
Nyankori and Miller (1982)	Quarterly	1965.00-1979.50	Ad hoc	Beef -0.11 Pork -0.39 Chik -0.70	0.22 0.60 0.71	BP 0.41 PB 0.28 CB 0.54	BC -0.11 PC 0.20 CP -0.38
Wohlgenant and Hahn (1982)	Monthly	January 1965-June 1979	Dynamic model short run	Beef -0.49 Pork -1.25 Chik -0.14	0.51 0.27 0.49	BP 0.23 PB 0.60 CB 0.08	BC -0.20 PC 0.15 CP 0.0
			long run	Beef -0.43 Pork -0.84 Chik -0.30	0.45 0.18 1.06	BP 0.20 PB 0.40 CB 0.18	BC -0.17 PC 0.10 CP 0.02
Heien (1983)	Quarterly	1967.00-1979.75	Almost complete system	Beef -0.95 Pork -0.95 Bril -0.47	0.94 0.32 0.65	BP 0.13 PB 0.26 CB 0.24	BC 0.04 PC 0.04 CP 0.11
Chavas (1983)	Annual	1970-1979	Ad hoc model without structural change	Beef -0.86 Pork -0.71 Plty -0.54	0.56 0.44 0.05	BP 0.23 PB 0.22 CB 0.26	BC 0.07 PC 0.06 CP 0.22
			with structural change	Beef -0.62 Pork -0.72 Plty -0.58	0.18 0.43 0.28	BP 0.36 PB 0.22 CB 0.30	BC 0.08 PC 0.08 CP 0.001
Huang (1985)	Annual	1953-1983	Ad hoc model	Beef -0.62 Pork -0.73 Chik -0.11	0.45 0.44 0.36	BP 0.11 PB 0.19 CB 0.29	BC 0.06 PC 0.09 CP 0.26
Eales and Unnevehr (1987)	Annual	1965-1985	Almost ideal demand system	Beef -0.57 Pork -0.76 Chik -0.28	0.34 0.28 0.53	BP 0.17 PB 0.31 CB 0.25	BC 0.05 PC 0.007 CP 0.02

[a]Chik = chicken; Plty = poultry; and Bril = broilers.
[b]Nine possible cross-price elasticities exist for each study. Two-digit codes identify the percentage change in quantity variable (first digit) that changes with a 1 percent change in the price variable (second digit). The following code definitions are used: B = beef; P = pork; C = chicken, poultry, or broilers, whichever applies.

Table 16. Forecast performance statistics for chicken model, 1987.00 to 1987.75

Variable	Label	RMPSE[a]
Chicken, broiler-type placements	CPLACE	0.04
Chicken, broiler-type hatches	CHATCH	0.02
Chicken, broiler production	CPROD	0.02
Chicken, other chicken production	OCPROD	0.28
Moving average of chicken placement	BRPL	0.03
Chicken, per capita consumption	PCCK4	0.03
Chicken, retail price of broilers	RPCK	0.08
Chicken, wholesale price of broilers	WPCK	0.18

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

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

Table 17. Forecast performance statistics for turkey model, 1987.00 to 1987.75

Variable	Label	RMPSE[a]
Turkey, total poults hatched	THATCH	0.07
Turkey, total production	TPROD	0.06
Turkey, ending stock of frozen turkeys	TENDSTK	0.26
Turkey, wholesale price	TWHP	0.19
Turkey, retail price	TRTP	0.03
Turkey, farm price	TFMP	0.25
Turkey, total civilian disappearance	TCSUMP	0.09

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

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

Endnotes

1. South Atlantic refers to Delaware, Maryland, Virginia, West Virginia, North Carolina, South Carolina, Georgia, and Florida; south central refers to Kentucky, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Oklahoma, and Texas.

2. Northeastern refers to Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut; north central refers to Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas.

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

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