Modeling U.S. Broiler Supply Response: A Structural Time Series Approach

Crispin M. Kapombe and Dale Colyer

A structural time series model is used to estimate the supply response function for broiler production in the United States using quarterly data and a structural time series model. This model has the advantage of expressing trend and seasonal elements as stochastic components, allowing a dynamic interpretation of the results and improving the forecast capabilities of the model. The results of the estimation indicate the continued importance of feed costs to poultry production and of technology as expressed by the stochastic trend variable. However, seasonal influences appear to have become less important, since the seasonal component was not statistically significant.

The estimation of supply response for agricultural products requires a thorough understanding of the biological cycle involved in production. The specification of a valid supply model does not only involve good statistical properties; the model must also be in agreement with the postulates of economic theory within the context of biological realities. In the case of broiler production, the biological cycle has been modified over the last five decades as a result of advances in production technologies through genetic research and development, improvements in broiler nutrition (e.g., less than 2 pounds of feed are required for 1 pound of broilers produced), and improved management practices. A broiler required 14 weeks to reach 3.5 to 4.5 pounds of body weight in the 1940s, but today only 7 to 8 weeks are required to attain this weight. Other innovations have affected reproduction traits, resulting in an increase in the number of hatchable eggs per breeder hen, a consequent increase in the number of broilers produced per hen, and a reduced cost per bird produced (Golz et al. 1990).

The goal of this study is to estimate the supply response for broilers and provide information that could assist managers and policymakers in planning growth strategies for the broiler industry. A focus of the analysis is on testing different lengths of lags for the broiler supply variables to verify the results established by previous studies (Aradhyula and Holt 1989; Chavas and Johnson 1982; Goodwin, Madrigal, and Martin 1996).

The model consists of a structural time series model (STSM) that can be recast in state-space representation and estimated by means of the Kalman filter method. The primary advantage of the STSM approach is the flexibility it provides in estimating models using time series data where trends and seasonal factors may complicate the econometric models (Harvey and Shepard 1993).[1] Frequently, these components have been included in supply models as linear (or nonlinear) time variables for trends and dummy variables for seasonal factors (see, for example, Aradhyula and Holt 1989; Chavas and Johnson 1982). However, those approaches tend to be deficient because of the dynamic nature of the structure of the phenomena under investigation, i.e., when there are trend or seasonal components that tend to change during the study period (are stochastic). Flexibility is achieved in the STSM approach by allowing the parameters to vary over time. This is accomplished through the state-space form with the state of the system represented by the unobserved components (trends and seasonals). Filtering techniques (the Kalman filter) are used to update the unobservable components as new data are added (Harvey 1989, 1994; Harvey et al. 1986; Gonzalez and Moral 1995; West and Harrison 1989). This procedure obtains parameter values that are reflective of the situation at the end of the study period and that tend, therefore, to result in more accurate short-term forecasts than are obtained from models

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where the parameters are based on the best fit over the entire data period. As Harvey and Shepard (1993, p. 261) indicate: "The principal univariate time series are therefore nothing more than regression models in which the explanatory variables are functions of time and the parameters are time-varying."

Background

Several studies have analyzed poultry supply response. Malone and Reece (1976), Chavas and Johnson (1981, 1982), Aradhyula and Holt (1989), and Goodwin, Madrigal, and Martin (1996) have estimated the impacts of economic variables on production, consumption, and prices in the U.S. poultry sector. Using quarterly data, Chavas and Johnson (1982) and Aradhyula and Holt (1989) found that the supply response of broilers was determined by the wholesale price of broilers, cost of feed, and hatch of broilers, all lagged one quarter. Using monthly observations, Goodwin, Madrigal, and Martin (1996) found that the supply response for broilers was determined by the real price of broilers lagged eight months, the cost of feed lagged eight months, and a twelve-month moving total of breeder pullet placements lagged eleven months.

Some studies reported a seasonal effect on the production of broilers (Malone and Reece 1976; Chavas and Johnson 1982; Wescott and Hull 1985; Bhati 1987). Malone and Reece (1976, p. 414) found that "the production and consumption of broiler meat varies seasonally and is accompanied by seasonally fluctuating prices. Seasonal variations in production also occur such that some monthly market clearing levels of price and quantity are the results of shifts in both the demand and supply relations." Seasonal factors in these models were represented with dummy variables.

A few studies examined the importance of the rational expectations hypothesis (REH) in poultry (broiler) supply response (Huntzinger 1979; Goodwin and Sheffrin 1982; Aradhyula and Holt 1989). Aradhyula and Holt (1989, p. 892) concluded that "the rational expectation of price variance is an important determinant of broiler supply."

The Structural Time Series Approach

Structural time series models (STSMs) have been proposed by Harvey and others in a number of papers and monographs (Harvey 1989, 1994; Harvey et al. 1986; Gonzalez and Moral 1995). These models are formulated directly in terms of components of interest, trend, seasonal, cyclical, and residual (irregular) components. In this type of model, the explanatory variables enter into the model side by side with the unobserved components. In the absence of such components, the model reverts to a standard regression (Harvey 1989, p. 12). A supply model, such as a broiler supply, takes the following general form:

$$Q_s = f(\mu, \lambda, \beta_i X_i, \varepsilon),$$

where Q_s is the quantity supplied, μ is the trend component, λ is the seasonal component, β_i are regression coefficients, X_i are the independent variables, and ϵ is the error term.

The stochastic formulation proposed for the trend component is more flexible (see Harvey 1989, 1994) since it allows the level, μ_t, and the slope, β_t, to evolve over time, thus:

$$(1) \qquad \begin{aligned} \mu_t &= \mu_{t-1} + \beta_{t-1} + \eta_t \\ \beta_t &= \qquad \beta_{t-1} + \zeta_t, \end{aligned}$$

where η_t and ζ_t are normally independent white noise processes with zero mean and variance σ^2_η and σ^2_ζ, respectively. This model is a local approximation to a linear trend; it collapses to a deterministic global trend when $\sigma^2_\eta = \sigma^2_\zeta = 0$. A stochastic trend component (μ_t) is included in a supply equation to capture the changes in variables such as productivity, technical progress, and structural change.

A stochastic seasonal component (γ_t) is added to the model to account for fluctuations in the supply responses during a year due to recurring changes in prices, weather, and other seasonal factors. The process generating the seasonal component is:

$$(2) \qquad \gamma_t = -\sum_{j=1}^{s=1} \gamma_{t-j} + \omega_t, \qquad t = 1, \ldots, T,$$

where ω_t is a normally distributed independent white noise process with zero mean and variance σ^2_ω, and s is the number of "seasons" in the year. Seasonality changes slowly by means of a mechanism that guarantees that the sum of the seasonal factors over any consecutive time periods has an expected value of zero and a variance that remains constant over time. The smaller the variance, the more stable the component.

Economic Model Specification

Following Aradhyula and Holt (1989) Labys and Pollack (1984), and Martinez et al. (1986) the broiler supply response structural time series model is specified as:

$$QBP_t = \mu + \gamma + \beta_1 WPBr_{t-4} + \beta_2 PBF_{t-4} + \beta_3 HATCH_t + \beta_4 QBP_{t-1} + \epsilon_t \quad (3)$$

where QBP_t is quantity of broiler production, million of pounds; $WPBr_{t-4}$ is the wholesale price of broilers lagged four quarters (dollars per thousand pounds); PBF_{t-4} is the real price of broiler feed lagged four quarters (dollars per pound); $HATCH_t$ is the hatch of broilers in commercial hatcheries (thousand head); QBP_{t-1} is broiler production lagged one quarter (thousands of pounds); and μ_t and γ_t represent the stochastic trend and seasonal components, respectively, where their specifications follow equations (1) and (2).[2]

The only input price included is for feed determined as a weighted average of prices of corn and soybean meal. As Rogers (1979) indicates, feed costs have historically accounted for 64% to 73% of total broiler production costs. A ton of feed now produces 37% more broilers and 54% more turkeys than in 1955 (Lasley 1983). Consequently, the feed cost variable should reflect the more important changes in short-run production costs. Feed cost (*PBF*), wholesale broiler price (*WPBr*), and commercial broiler hatch (*HATCH*) could assume a one-quarter delay or more in response to changing profitability.[3] Broiler producers may not fully adjust production to a desired level during any given quarter because of capital constraints, adjustment costs, and fixed contract periods. Aradhyula and Holt (1989) and Chavas and Johnson (1982) used one-quarter lags in their models but Goodwin, Madrigal, and Martin (1996) found lags varying from eight to twelve months in their model that used monthly data. Thus, different lags for the dependent variables were tested manually and the best combination was selected and included in the supply response model. The coefficients for *WBPr*, *HATCH*, and *QBP* terms are expected to be positive, whereas that for *PBF* is expected to be negative. The signs on the stochastic trend and seasonal components are not predetermined.

The broiler supply response STSM with explanatory variables is a generalization of the classical linear regression model. If the variances of hyperparameters (trend, level = σ^2_η and slope = σ^2_ζ) and seasonal ($\sigma^2\omega$) are zero, the equation collapses to a standard regression equation with a linear deterministic trend and a seasonal component, in addition to the explanatory variables. Specification of the broiler supply response model assumes that the dependent variable is not stationary and that first difference and seasonal differences should be taken to achieve stationarity. Therefore, this model also includes, as a particular case, the model with a differenced dependent variable (see Gonzalez and Moral 1995; Harvey 1989).

Data

Data for model estimation are quarterly values that cover a more recent period than previous studies, from the first quarter of 1970 through the fourth quarter of 1993.[4] Data from 1994 and 1995 are used to check the forecasting performance of the model. The broiler supply response functional relationship is assumed to be linear in parameters to simplify the estimation and subsequent dynamic analysis of the model. Quantity variables are in per capita terms and prices are expressed and estimated in real values to preserve the linearity of the system and to allow the straightforward induction of the linear (in parameters) structural form from the structural estimates for the broiler supply response model specification (see Chambers and Just 1981, p. 33).[5] The variables are transformed into logarithms so that their parameters represent the elasticities taken as constant over the sample period.

Results

In this section, the analyses of the trend and seasonal components are presented first. Then the estimated model is presented and discussed. This is followed by an examination of the dynamic characteristics of the model. The final subsection deals with the forecasts made with the estimated model.

Trend Component

Testing for trends in the broiler supply variable series is a two-step process. First, the *stationarity property* of the series is estimated using the Augmented Dickey-Fuller (ADF) (1979) and the Phillips-Perron (PP) (1988) tests. Table 1 reports the results of the tests for the broiler supply variable series. In most of the cases, the broiler supply variable series remained nonstationary, no matter whether the original ADF equation or its modifications with a constant or with a constant and trend are used. The broiler supply series was stationary in only one case, when both a constant and a trend were excluded from the model. The broiler supply variable series was then first-differenced, and this resulted in stationarity for the series.

The results of the PP test indicated that the broiler supply series is stationary for first differences only, whether or not a trend and/or a constant

Table 1. Unit Roots Test Results, 1970.1–1993.4

k = 0		Augmented Dickey-Fuller (ADF) Test			Phillips-Perron (PP) Test		
Variable Series		———	c	(c) + βt)	———	c	(c) + βt)
Broiler supply	QBP^L	3.19**	−1.04	−1.28	2.9	1.05	−1.31
	ΔQBP	−11.67*	−12.35*	−12.56	−11.7*	−12.35*	−11.57*

L = Broiler supply in level.
* = Significant at 1% level.
** = Significant at 5% level.
Δ = First difference of the variable.
Critical values: −2.58 to 4.025 (at 1% level of significance); −1.94 to 3.44 (at 5% level of significance).

is included. The outcome of these tests is that the presence of stationarity in the broiler supply model variable series is mixed and indicates that the underlying trends might be stochastic rather than deterministic (see Harvey 1989, p. 30). Although the first differencing of data may be advocated to avoid the risks of incorrect inferences, not only about stationarity due to the presence of unit roots, the dangers of over differencing are as grave (see Harvey and Jaeger 1993, p. 231). This suggests that the broiler supply STSM should be specified in levels, but that the trend component should be stochastic in level and in growth rate.

Seasonal Components

A two-step procedure also is used to identify possible seasonal components. Since the broiler supply model data are quarterly, it is appropriate to include a seasonal component in the model specification. As the first step, the broiler supply variable series (*QBP*) is plotted (figure 1). The plots are based on the percentage differences from the trend line. Figure 1 consists of two parts: the first plot shows combined data for all four quarters within each year and the second presents trend lines for each of the four quarters. The results suggest the presence of a seasonal pattern in the series, justifying its inclusion in the model. However, the plots also show that the seasonal patterns have evolved over time, becoming much less pronounced in recent years.

The second step consists of the estimation of the selected model. The features of the output directly relevant to seasonal effects are as follows: (1) the seasonal hyperparameter is nonzero, indicating that there are changes in the seasonal pattern; (2) the state has s-1 (4-1 = 3) elements to capture seasonality; (3) finally, the importance of the seasonal factor is assessed by means of the ''seasonal test,'' which is an output of the final state dialog. This tests the statistical significance of the seasonal pattern at the end of the period. It is asymptotically chi-square. The test is assessed in conjunction with a full plot of the seasonal component. The results of the test indicate that all seasonal components are nonsignificant in the broiler supply equation; thus they are omitted from the final model. It should be noted that while the seasonal component has become smaller and was nonsignificant at the end, it was statistically significant the beginning of the study period. The nonsignificance of the seasonal component is in contrast with the results of Chavas and Johnson (1982) and Aradhyula and Holt (1989), whose estimated models included seasonal dummy variables that were statistically significant.

Statistical Tests of the Estimation Results

The results of estimating broiler supply response structural model (final state vectors, explanatory variables, and hyperparameters) with the STAMP 5.0 statistical package are presented in table 2 and discussed below (see Koopman et al. 1995). As indicated below, the goodness of fit diagnostics for the broiler supply model are satisfactory.

In table 2, N is the Jarque and Bera statistic for testing normality, which follows asymptotically a χ^2 distribution with two degrees of freedom under the null hypothesis. N = 0.78 while the 5% critical value of the $\chi^2_{(2)}$ is 5.99, indicating that the null hypothesis of the presence of non-normality in the residuals should not be rejected. This diagnostic shows that there is no indication of non-normality in the residuals.

Q(P) is the Box-Ljung statistic, based on the first P residual autocorrelations. $Q_{(9)}$ = 5.41 and the 5% critical value of the $\chi^2_{(9)}$ distribution is 16.92. The decision rule is to reject the null hypothesis of the presence of serial correlation in the residuals if the calculated value is greater than the critical value. This diagnostic test is clear-cut, indicating that there is no serial correlation in the residuals.

H(m) is a test for heteroscedasticity (unequal variances). $H_{(29)}$ = 0.71 and the 1% critical value

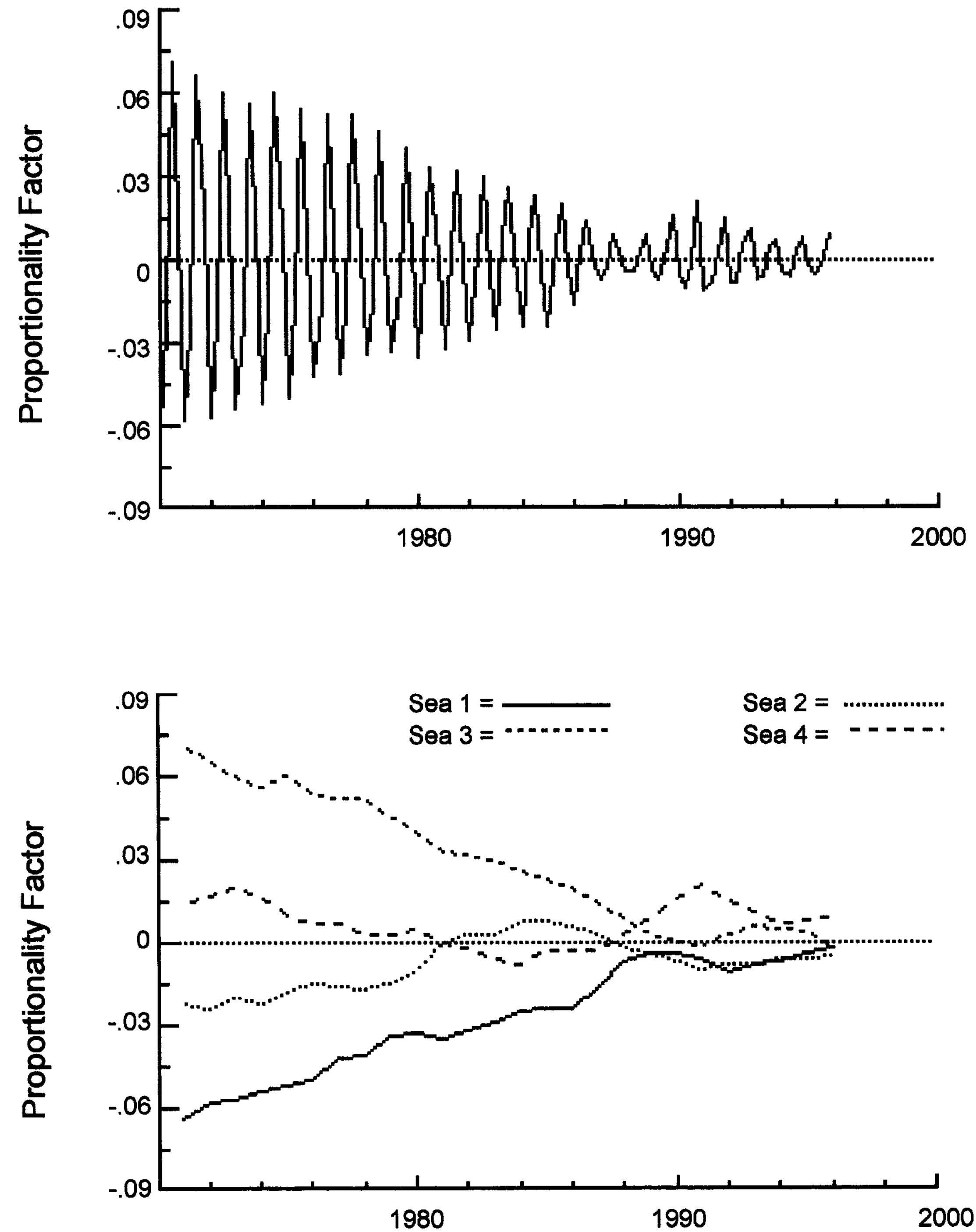

Figure 1. Plot of Seasonal Values and Trends, 1970–95

of $F_{(29,29)}$ is 2.56, indicating that the null hypothesis for the presence of heteroscedasticity in the residuals should not be rejected, i.e., there is no indication of heteroscedasticity in the residuals.

Since the R^2 is not very useful as a measure of goodness of fit when analyzing time series that exhibit strong upward or downward trends and/or seasonal cycles, Harvey (1989, pp. 263–69) proposes new coefficients of determination: R^2_D obtained by substituting the observations by their first

Table 2. Maximum Likelihood Estimates of the STASM Broiler Supply Model

Variable	Quarters Lagged	Symbol	Coefficient	Standard Error
Trend	N.A.	*(μ)*	1.540*	0.260
Wholesale broiler prices	4	*WPBr*	0.069*	0.063
Broiler hatch	0	*HATCH*	0.730*	0.063
Broiler feed price	4	*BPF*	–0.050**	–0.030

*Significant at the 1% level.
**Significant at the 10% level.
Std. Error = .019; N = 0.78; Q(9) = 5.41; H(29) = .71; R^2_D = .85; R^2_S = .51; DW = 1.95; σ^2_η = 00; σ^2_ζ = 00; σ^2_ω = 00; $\sigma^2_\epsilon = 1.8 \times 10^{-4}$; $\sigma^2_p = 3.62 \times 10^{-4}$; LogL = 325.3.

differences, or R^2_S, if the series presents seasonal behavior, obtained by substituting the observations by the first differences of the series around the seasonal means. $R^2_D = 0.85$ and $R^2_S = 0.51$ represent the measures of goodness of fit for the broiler supply response model. R^2_D is most useful when the series appears to be stationary with no trend and seasonal components. Any model that has R^2_S negative can be rejected, whereas if R^2_S is positive but close to zero, the gains from what is presumably a more complex procedure are marginal.

The Durbin-Watson (DW) statistic is distributed approximately as N(2, 4/T) and used as a calculated value for the Durbin-Watson test for autocorrelation of the disturbances. The broiler supply model DW is above 1.50. This suggests that there is no autocorrelation in the disturbances.

Thus, the diagnostics indicate that the broiler supply response model is appropriate for the data. The broiler supply response model appears to fit well and achieve a sound level of statistical significance, as evidenced by the associated standard errors (SE) and root-mean-square errors (RMSE) or standard deviations (SD) for the estimated parameters. The signs of all coefficients appear to be reasonable in terms of a priori expectations.

The hyperparameters (σ^2_η, σ^2_ζ, σ^2_ω, and σ^2_ϵ), evaluated at the end of the sample period, are fundamental parameters in the broiler supply response structural model. They govern the movements in the components and give information on goodness of fit of the estimated structural model. The maximum likelihood estimates of the variances estimates of the white noise disturbances for the trend (level and slope), seasonal, and irregular components (σ^2_η, σ^2_ζ, σ^2_ω, and σ^2_ϵ) show that most of the variances are zero or close to zero. A zero parameter value means that the corresponding component is fixed. Thus, in the present case, the trend (level and slope), seasonal, and irregular components are almost fixed. The highest value is 0.00018. Lower values of the variances estimates show that the diagnostics are satisfactory for the broiler supply response model. The prediction error variance estimate (σ^2_p) is low and equal to 0.00036 in the broiler supply response model. The log-likelihood (LogL) is the actual function at its maximum. Its value is 325.3 for the broiler supply response model and, based on the magnitude of the variances, prediction error variance and the log-likelihood estimates, the goodness of fit is satisfactory for the broiler supply response model.

Discussion of Results

The values reported in table 2 represent those for the trend component and statistically significant explanatory variables at the end of the sample period.[6] The best results were observed when the price of broilers was lagged four quarters. A four-quarter lag also was found to produce the best result, based on statistical and economic properties, for the broiler feed price variable. However, the broiler hatch variable yielded the best results when it was not lagged (zero-quarter lag)—a situation that may be explained by technological progress in the broiler industry.

These results indicate that commercial broiler slaughter is closely related to the hatch ($HATCH_t$) in the same quarter. A 1% increase in broiler hatch would increase broiler supply by 0.73%. The elasticities on the *HATCH* variable, when lagged up to four quarters, were close to zero and not significant. There is usually enough excess capacity maintained at the hatchery supply flock level to assure a sufficient degree of production flexibility.

The broiler grower feed price variable lagged four quarters (PBF_{t-4}) is, as expected, negatively related to broiler supply. The supply elasticity with respect to feed price is –0.052 and well within the range of previously reported estimates (e.g., Aradhyula and Holt 1989; Goodwin and Sheffrin 1982; Chavas and Johnson 1982). A one percent increase in the broiler grower feed price would decrease broiler supply by .052 percent. Also, changes in productivity and technology, represented by a stochastic trend component, are positively related to broiler supply.

The supply elasticity with respect to the trend variable is 1.54, well above the range of previously reported estimates when the trend is deterministic (see, e.g., Goodwin and Sheffrin 1982; Chavas and Johnson 1982). Technical advancements are evident from lower input requirements for poultry production; whether these can be sustained so that the trend component remains as strong as estimated in this model will depend on research, management, and other changes that cannot be predicted although they have persisted for a number of decades. Finally, the broiler supply appears to be responsive to its own-price movements lagged fourth-quarters, although in an inelastic sense. The elasticity of supply with respect to wholesale price is 0.069. In studies related to agricultural supply response, it is typical to find that agricultural supply exhibits an inelastic response to market prices (e.g., Childs and Hammig 1989).

No seasonal component (γ_t, γ_{t-1}, γ_{t-2}) was statistically significant in the broiler supply model. This point is relevant to broiler supplies, where the seasonal effect has become smaller over time as the broiler industry has become less dependent on seasonal factors, as shown by figure 1. The first part of figure 1 graphs all four seasons and shows how the seasonal component has declined during the study period; the second part graphs the trends for each of the four seasonal components and indicates that each season's variations have become much less intense. This result contrasts with previous studies' findings. By assuming that seasonal patterns were deterministic (e.g., represented by dummy variables) instead of stochastic, some studies (Malone and Reece 1976; Chavas and Johnson 1982; Goodwin, Madrigal, and Martin 1996, etc.) reported significant seasonal effects on the production of broilers.

Dynamic Characteristics of the Model

Expressing the model as a first order, linear difference equation system permits studying the dynamic behavior of the model with standard procedures of linear system analysis. The most important questions when investigating changes in exogenous variables relate to the total or long-run effects of such changes after a new equilibrium has been reached. Table 3 reports the dynamic (interim) multipliers associated with those changes for the current period and lag periods of one to four quarters. Given the ability of broiler producers to adjust production (for example, it takes seven to eight weeks to produce a 3.5 to 4.5 pound broiler) in response to changing profit conditions, these multipliers (calculated after four quarters) represent a fairly long and smooth adjustment process once the initial shocks are over. Also, the selection of up to a four-quarter-lag structure is consistent with the study by Goodwin, Madrigal, and Martin (1996, p. 37). Analyzing the broiler supply and demand responses, these authors identified the dynamics of the relationships displayed by consumers and producers of broilers by using different economic variables lagged up to eight and eleven months. After this period, the market forces cease to have discernable effects and the changes in the exogenous variables become random.

The results suggest that in the long run the wholesale price of broilers, broiler feed price, and hatch of broilers have impacts on broiler supply responses (table 3). A sustained 1% increase in the broiler wholesale price would cause broiler supply to increase by 0.13% in the long run (total effects), compared with an increase of 0.057% and 0.048% in the current period and after one quarter, respectively. The short-run impacts, captured by the reduced form equation, were a 0.069% change in the broiler supply for a 1% change in wholesale price of broilers. Also, a sustained 1% increase in broiler feed price would cause broiler supply to decrease by 0.102% in the long run (total effects), compared with −.051% and −.027% in the current period and after one quarter, respectively. Short-run impacts were a −.050% change in broiler supply for a 1% change in broiler feed price. Finally, a sustained 1% increase in the hatch of broilers would cause broiler supply to increase by 1.5% in the long run (total effects), compared with 0.77% and 0.73% in the current period and after one quarter, respectively. Although the long-run elasticity may seem

Table 3. Dynamic Multipliers for a 1% Change in Exogenous Variables on U.S. Broiler Supply Response

	Exogenous Variables								
	Wholesale Price of Broilers			Hatch of Broilers			Broiler Feed Price		
Endogenous Variable	Impact[a]	Interim[b]	Total[c]	Impact[a]	Interim[b]	Total[c]	Impact[a]	Interim[b]	Total[c]
Broiler supply	0.057	0.048	0.130	0.770	0.730	1.50	−0.051	−0.027	−1.02

[a]The impact multipliers refer to the current-period (zero-period lag) effect of a change in the exogenous variable on the broiler supply response.
[b]The interim multipliers refer to one-quarter-period lag effects of changes in the exogenous variable on the broiler supply response.
[c]The total multipliers refer to the situation where the increase in the exogenous variables is sustained for a four-quarter-period lag.

excessive, it should be noted that while the hatch in the current period has little direct effect on production beyond the current and next period, increases in the hatch of broilers may signal a need to expand breeder facilities and numbers of pullets to be placed, both of which require a longer time for implementation.

Forecasting Results

Forecasting performance of the broiler supply response model is evaluated using ex-post predictions. Forecasts are made from the broiler supply response structural model estimates for the period from the first quarter of 1994 through the fourth quarter of 2005, based on realized values of stochastic components (trends and seasonals) and predetermined variables and utilizing Kalman filter techniques. The forecasting performance of the model is evaluated by comparing these forecasts with the true values of the corresponding variables for the 1994–95 period. Root-mean-square errors and directional change prediction criteria are used to evaluate the forecasting ability of the model.

The forecasts, together with their estimated root-mean-square errors and actual broiler supplies, are shown in table 4. Fitting quarterly STSMs leads to good forecasts, with a 32% smaller RMSE for the first one-quarter ahead forecast (i.e., an RMSE savings for the 1994 quarter 1 forecast compared with that for 1994 quarter 2). This savings tends to zero as the forecast horizon increases, and the forecasts tend toward the mean values of the broiler supply time series variables (other periods have a 1.56% to 15.78% savings on RMSE). The forecasts values for each of the quarters in 1994 and 1995 are close to the averages for broiler supplies, indicating that the model predicts the real situation effectively, at least for a short period of time. Another way of interpreting the broiler supply model forecasting results is to look at the prediction of a directional change. Forecast and actual values of the broiler supply response model variable shown in figure 2 indicate that a directional change was correctly forecast in the 1994–95 period.

Table 4. Broiler Supply Forecasts

Years	Forecast	RMSE	Actual
1994.1	21.67	0.31	21.65
1994.2	22.87	0.46	22.82
1994.3	23.33	0.47	23.45
1994.4	22.82	0.48	22.87
1995.1	23.16	0.57	23.26
1995.2	24.17	0.61	24.01
1995.3	24.14	0.63	23.29
1995.4	24.13	0.64	23.84
1998.1	25.27	1.18	—
1998.4	26.13	1.35	—
2000.1	26.66	1.80	—
2000.4	27.57	2.05	—
2002.1	28.14	2.59	—
2002.4	29.11	2.92	—
2005.1	30.57	4.14	—
2005.4	31.64	4.61	—

Conclusions

The results of the estimated models were generally good. Per capita broiler production proved to be determined by four-quarter lags for broiler prices and feed prices and the broiler hatch in the same quarter. This finding contrasts with the previous studies reporting a one-quarter lag for both variables (Chavas and Johnson 1982; Wescott and Hull 1985; Aradhyula and Holt 1989), and it appears that the increasingly integrated industry permits production decisions to be made over longer periods of time than in the past. This study's results confirm the influence of technological innovations on the broiler cycle and reproduction traits. These results are consistent with the findings by Goodwin, Madrigal, and Martin (1996, pp. 40–41). Using monthly data, these authors estimated an alternative broiler supply-response model in which all independent variables had lags of eight to twelve months. These lags are reasonable given the biological cycle involved in the broiler production process. The length of the breeder hen production cycle is about ten to twelve months, with an additional one to three weeks to clean up between batches before another production cycle takes place (Chavas and Johnson 1982, p. 559).

The response of broiler supply to own-price changes was found to be inelastic in the short run (0.069) and long run (0.13). In studies related to agricultural supply response, it is typical to find that agricultural supply exhibits an inelastic response to market prices (e.g., Childs and Hammig 1989). Also, this result is consistent with those established by previous studies related to broiler supply response: Chavas and Johnson (1982, p. 560) found own-price elasticity of 0.023; Aradhyula and Holt (1989, p. 899) obtained an elasticity of 0.022 (with respect to the broiler expected price); the estimate by Goodwin, Madrigal, and Martin (1996, p. 25) was 0.016.

Feed prices and technological progress are significant determinants of U.S. broiler supplies. The biological cycle of broiler production has been modified, reproduction traits improved, and labor costs reduced. The results reported in this study

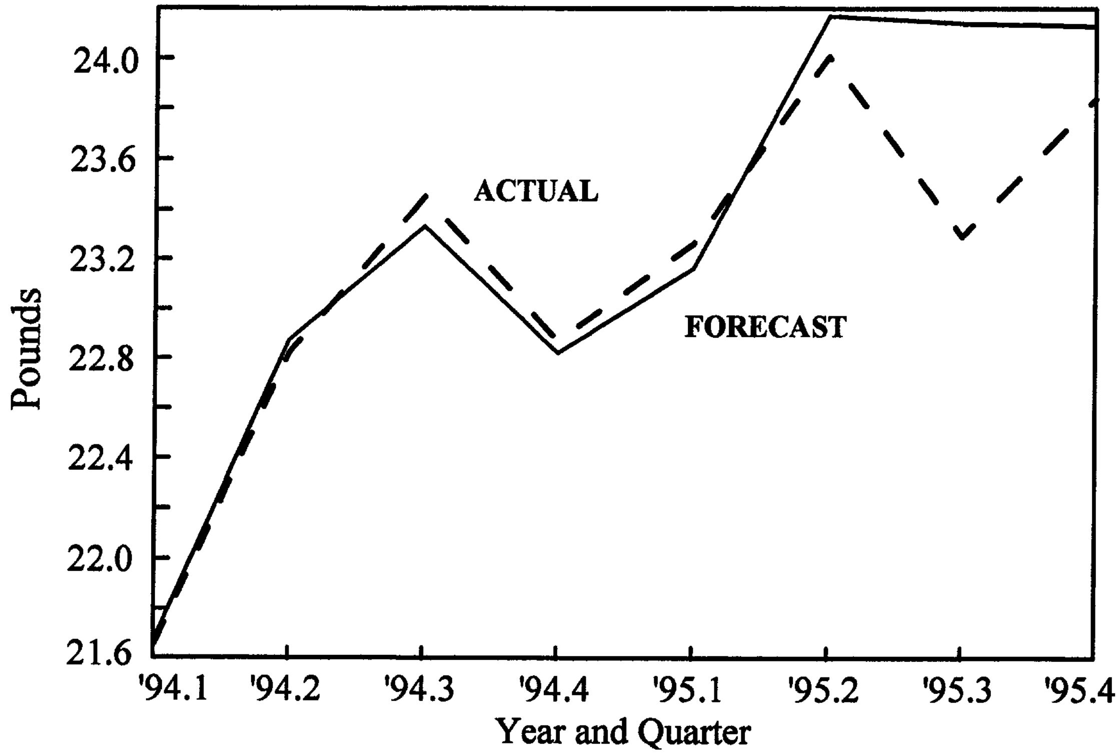

Figure 2. Forecast and Actual Broiler Supplies, 1994(I)–95(IV)

are, in part, a reflection of these changes in the broiler technology. The broiler supply elasticity with respect to the trend variable is 1.54, suggesting that a 1% improvement in productivity and technology (and perhaps other factors) is associated with 1.54% increase in broiler supplies.

The broiler grower feed price variable, as hypothesized, is negatively related to broiler supplies. The study found that a sustained 1% increase in broiler feed price would cause broiler supplies to change, in the long run, by –0.102%. Also, a sustained 1% increase in the hatch of broilers would cause broiler supplies to increase by 1.5% in the long run. These findings are consistent with the fact that feed cost is the most important input used in the production of broilers, representing about 70% of the total cost of live birds (Lasley et al. 1988). Another 16% is accounted for by the cost of baby chicks (Benson and Witzig 1977). The cost of baby chick production (hatch of broilers) is, in turn, largely determined by feed costs, so that the feed price coefficient captures most of the short-run costs.

An additional finding was that, currently, there is no significant seasonal effect on the production of broilers. This result is relevant to broiler supplies, where seasonal effects have become smaller over time, indicating that the broiler industry has become less dependent on seasonal factors as chicken has become a staple diet item instead of a food for special occasions or certain times of the year.

Knowledge of the variables that influence U.S. broiler supply response can be of assistance to policy makers in planning growth strategies for the broiler industry. This is particularly important for broiler producers, processors, and others connected with the industry and trade in poultry products. The results reported in this study lead to the following conclusions and policy implications.

The supply response model results can be useful for policymakers and managers of broiler companies because quarter-by-quarter changes in the future production of broilers can be estimated up to four quarters in advance. The knowledge of the probable output levels would be useful for making optimal managerial decisions regarding financial and marketing strategies. In addition, the impact of potential changes in the real price of broilers, broiler chicks hatched, and feed ingredient costs (price of broiler feed) upon total production has been estimated through dynamic multipliers analysis. This result can be helpful in evaluating the impacts of changes in farm programs.

Because much of the cost of producing poultry can be attributed to feeds, price policies and protection afforded to both feed grains and oilseeds (particularly soybeans) can produce important effects on the poultry market. For example, adjustments to feed prices resulting from the 1996 Federal Agricultural Improvement and Reform (FAIR) act—or from any other factor affecting feed grain or soybean prices—are likely to cause simultaneous shifts in the broiler supply function and, consequently, the demand function for feeds, thus influencing quantities produced and feed inputs as well as prices. The price of feed may rise because of the removal of production subsidies in the form of deficiency payments and, thus, increase poultry production costs and decrease supplies. Falling supplies, other things being equal, would tend to raise wholesale poultry prices and increase costs to consumers. To keep the industry profitable, wholesale poultry prices *might* have to rise more than the feed prices, making poultry meat more expensive.

Given the results of this study, the advantages of STSM, formulated directly in terms of unobserved components such as trends and seasonals, make it an attractive methodology in the context of modeling broiler supply response. The introduction of a stochastic trend component in the econometric model is a powerful tool to proxy the influence of unobserved variables such as changes in productivity and technology. The analysis of the contribution of the explanatory variables to the growth of broiler supply response has shown that a trend component has been vital in the expansion of the broiler industry during the study period. Also, use of quarterly data for the models provides results that produce accurate short-term forecasts of the future values for the broiler supply variable.

More work is required to extend this study's framework to include, where possible, social, political, environmental, and waste impacts in the model's specification, estimation, forecasting, and policy analysis; this will permit a more complete identification of factors affecting broiler supply response. There also is a need to investigate the effect of seasonal pattern on the broiler supply response and to formulate a supply-demand simultaneous model to capture all the interrelated effects between price and quantity.

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Notes

1. Cyclical relationships also can be accommodated by STSMs.

2. Although QBP_{t-1} and γ are included in equation (3), they are not significant and are omitted from the final model.

3. Most of the biologically based lags in broiler supply response analysis—for example, the time required for adjusting the size of the broiler breeder flock—substantially exceeds the one-quarter lag utilized by previous authors (see Chavas and Johnson 1982; Aradhyula and Holt 1989), although Goodwin, Madrigal, and Martin (1996) found lags varying from eight to twelve months. A four-quarter lag is an approximation of time required for growing a breeder pullet, having her produce her first hatchable eggs, and growing, slaughtering, and processing the offspring from the hatch. Thus, response to variables such as price received for broilers or the cost of feed may occur at a variety of critical decision points. For example, adjustment to changes in these variables may be reflected in the decision to place breeder pullets four quarters prior to the time that the result of that decision can emerge in the marketplace. Further adjustments to such changes can occur in the selection of eggs to be placed in the incubator, in the minimum acceptable size of the hatching eggs selected, and when the chicks are hatched and surplus chicks may be destroyed.

4. Quarterly quantities for broiler supply, hatch, broiler prices, and feed prices were obtained from the Livestock and Poultry Situation and Outlook, Poultry Outlook, all published by ERS-USDA. The Consumer Price Index (1982 to 1984 = 100) and U.S. population were obtained from the Survey of Current Business (U.S. Department of Commerce). Monthly data are available for the poultry model and are used by Goodwin, Madrigal, and Martin (1996). However, time series models using monthly observations tend to be less consistent and stable than those using quarterly data, which can capture most of the intrayear effects.

5. Although it is more common to use totals for quantity variables in supply response models, Chambers and Just (1981, p. 32) use per capita data in supply functions for corn, wheat, and soybeans for purposes of examining dynamic adjustments in their model.

6. The dependent variable with a one-quarter lag (QPB_{t-1}) was not statistically significant (although it had the expected sign). Thus, it was not included in the final model.