BROILER WATER DEMAND: FORECASTING WITH STRUCTURAL AND TIME SERIES MODELS

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Abstract. A profit maximization model and an ARIMA model were developed to forecast water demand for broiler production. Broiler production decisions are made in three successive stages -- primary broiler breeding flock, hatchery flock, and finishing broiler production. The forecasted numbers of broilers from structural and ARIMA models diverge significantly from a USGS physical model. Analysis indicates 15% slippage in water demand forecasting related to disregarding the role of economic variables. We find that an appropriate lag structure can fully capture the information used in structural models, assuming no structural change.

INTRODUCTION

Concurrent with the rapid growth of metropolitan areas, adverse climatic conditions and increasing water demand for agricultural and other sectors have created pressure on existing water resources in many parts of the United States (Jordan, 1998). However, efficient allocation of existing water is severely constrained by lack of information about present and future water demand by different sectors of water use, including animal agriculture (Hatch, 2000). Although small in comparison to many other sectors, precise estimates of future water demand for animal agriculture can play an important role in water allocation decisions.

Finding accurate information related to water use for animal agriculture is difficult, due to the scarcity of previous research and lack of systematic records of water use data. Except for aggregate animal water use data published by the United States Geological Society (USGS), there exists very little information about animal water use in the US. Unfortunately, USGS estimates of water demand are based on a static physical model whereby future water demand is a function of temperature, daylight, and physiological conditions of animals. The USGS water forecasting model carries limitations similar to other past water models by failing to capture the animal production behavior of farmers, which respond to economic and institutional changes.

Indeed, animal production involves decisions that are mostly driven by economic variables, such as expected future profits and costs of inputs. Supply of animals is also affected by changing international trade agreements, environmental laws, and other government programs. A sound supply response model and rigorous analysis are needed to accurately predict the number of animals, and thereby the amount of water demanded by animal agriculture. To our knowledge, this is the first study of broiler water demand forecasting to incorporate economic variables and represents a significant departure from previous studies.

MODEL DEVELOPMENT

We first select broiler production in Georgia for future water demand modeling purposes. For model development, we consider a competitive firm, where the production function can be decomposed into N production stages. At each stage, the producer makes a decision about selected variable inputs, and some form of capital is transformed into a different form of capital (Jarvis, 1974). Conceptually, we can represent this type of production function (following Chavas and Johnson, 1982) as $Y_k = f_k(Y_{k-1}, X_k)$, where k = 1, 2, …, n periods, Y_k = vector of capital stock at stage t, Y_{k-1} = lagged vector of capital stock, and X_k = vector of variable inputs used in the t^{th} production stage. Here, a vector of variable inputs X_k changes the capital Y_{k-1} into a different form of capital Y_k. In the case of poultry production, Y_1, Y_2, and Y_3 represent the placement, the grow-out flock, and broiler production, respectively. A vector of variable inputs, such as feeds and other nutritional supplements, changes poultry forms from one stage of production to another. In each stage, growers make economic investment decisions.

We next develop a profit function, and ignoring salvage value and considering the constraints of the production technology and profit maximization, which is used to show that economic decisions made at earlier stages define the optimality condition at each successive stage of broiler production. Introducing time variables at each stage of production allows us to examine the dynamics of the broiler production system. However, underlying production technology alters the time lag separating two successive stages of production. Although the time lag between two stages is mostly defined by the underlying production technology, there are instances in the production process where decisions influence a change in the lag between two successive stages, as when sudden changes in the prices of output or inputs occur. For example, an increase in the short-run profitability of egg production would be expected to reduce the culling rate of pullets or hatching flocks.

A REPRESENTATIVE BROILER MODEL

Today's broiler industry represents a rapidly changing and highly technical agricultural industry. In this vertically integrated industry, integrators control all or most of the production stages, and thereby investment decisions. Integrators generally own breeder flocks, feed mills, and processing plants. The integrators provide the chicks, medication, and other technical support to growers, and they also co-ordinate processing and marketing activities. Given the current nature of broiler production, the broiler production decision of our study area can be examined in three successive stages, namely: placement, hatching, and broiler production.

Understanding the underlying technology of broiler production process is critical for dynamic broiler supply decisions. In the broiler production process, after a few weeks of placing chickens in hatchery supply flocks, egg production starts, following a cycle of high and low production that generally lasts for 10 months in broiler-type chickens. After hatching, approximately eight weeks are needed to produce a 3.8-pound (lb) broiler carcass (at 72% dressing). These underlying time gaps between the different stages of broiler production offer insight to develop a dynamic broiler supply response function.

To fully compare forecasts of broiler production by econometric and physical models, and thereby water demand by broilers in Georgia, Autoregressive Integrated Moving Average Models (ARIMA) were also developed. ARIMA (p, d, q), where p, d, and q represent the order of the autoregressive process, degree of differencing, and order of the moving average process, respectively, were specified.

In the ARIMA models, the broiler supply response is modeled dependent on past observation of itself. Future prices of broilers were estimated by using Box-Jenkins (ARIMA) time series models, also. Quarterly data of 1967-2002 of broiler chick placement, hatching flock, and final broiler numbers of selected counties of Georgia were collected from National Agricultural Statistics Services (NASS) of United States Department of Agriculture (USDA) and Georgia Agricultural Facts. Wholesale prices of broilers and feed costs were collected from the Economic Research Service (ERS) of USDA, and were deflated by using the consumer price index (all urban consumers, US city) average (1982-84 = 100).

In our analysis, lagged observed wholesale output (broiler) price is considered to be the expected price for output (naïve expectations). Although such expectations are, in general, not rational, they reflect most of the information available to decision makers (Muth, 1961). In our model, dummy variables for second, third, and fourth quarters capture the effects of seasonality and a trend variable is used as a structural change proxy. Future feed costs and output prices were estimated by using a Box-Jenkins (ARIMA) specification. Water use coefficients for broilers were collected from the USGS.

It is possible to examine the estimated equations in various ways; however, the basic aim of this work was to examine how well the estimated equations track the historical behavior of the modeled supply relationship. Our analysis first presents a common econometric evaluation of the estimated parameters, the sign of each parameter, and the derived elasticities. This is followed by time series water demand forecasting.

In our analysis, the broiler placement equation represents a distributed lag model, raising the possibility of the autocorrelation problem. The autoreg procedure of SAS solves the problem of autocorrelation by augmenting the regression model with an autoregressive model for the random error, thereby accounting for the autocorrelation of the errors. By simultaneously estimating the regression coefficients and the autoregressive error model parameters, the autoreg procedure corrects the regression estimates of distributed lag model.

RESULTS AND DISCUSSION

Results of the broiler-breeder placement equation using this autocorrelation procedure are presented in Table 1. The following two phases use predicted results from the first recursively. To select the best model for the hatching and broiler production phases, stepwise selection procedures were used. The stepwise procedure combines both backward selection and forward selection to propose the chosen model. Results of the hatching and broiler production equations using the stepwise procedure are presented in Tables 2 and 3, respectively. In our analysis, the F statistics and P values (p = 0.0001) strongly reject the null hypothesis that all parameters except the intercept are zero. The estimated model explains historical variations in broiler production well, with an adjusted R^2 of 0.99 (Table 1).

Placement in the hatchery supply flock (BBPt) represents the first stage of broiler production. Only variables significant at the 90% confidence level are presented in Table 1. The estimated coefficients of chick placement and wholesale broiler price in the lag structure yield positive signs, findings consistent with Chavas and Johnson, 1982. Although insignificant, the estimated coefficients of the broiler feed price had negative signs. In our analysis,

Table 1: Broiler Chick Placement, 1967-2002

Variable	Coefficients	Standard Errors	P- Values
Intercept	-1.0985	7.376	0.8819
BBP_{t-4}	0.8762	0.0341	<0.0001
WBP_{t-1}	92.70	44.99	0.0517
T	0.3514	0.0675	<0.0001
Total R^2	0.9928		

elasticity of one-quarter lag broiler wholesale price was significant, and a one percent increase in the wholesale broiler price increases the introduction of chicks into the production process (placement) by 0.061%. A historical trend and technological advancement in broiler placement was captured by the positive coefficient of 0.3514 of the annual trend variable. The study results show no significant impacts of seasonal variables on placement.

In the hatching equation, the signs of the coefficients were consistent with expectations. The signs of the predicated placement variables on lag structure were positive and significant. As expected, wholesale broiler price had a positive sign and was significant, and the elasticity shows that an increase of 1% in wholesale broiler price would be accompanied by an increase in the expected broiler type chick hatching by commercial hatcheries by 0.729%. Feed cost elasticity in hatching stage of production indicates a decrease of 0.41% of birds at the hatching phase for every 10% increase in the feed cost. The study also shows significant seasonal impacts in the hatching phase.

Hatched chicks are generally fed for approximately eight weeks to get a marketable broiler weight. In our analysis of the broiler production equation (Table 3), lagged hatching variables, lagged wholesale broiler price, and broiler feed cost yield the expected signs. The wholesale price of broilers in the previous quarter showed a significant impact on current broiler production. The estimated elasticity for wholesale broiler price indicates a 0.078% increase in broiler production for every 1% increase in the wholesale broiler price. Broiler feed costs fail to show significant impacts on this stage of broiler production. This result was not consistent with the findings of other researchers (Aadland and Bailey, 2001; Freebairn and Rausser, 1975; Bhati, 1987; Mbaga, 2000), but may link back to its impact on the previous phase. That is, feed costs do not significantly impact current broiler finishing, but those costs do influence hatching placement and thus future finishing numbers.

Table 2: Broiler Hatching Flock, 1967-2002.

Variable	Coefficients	Standard Errors	P- Values
Intercept	1.761	6.961	0.8008
PPL_{t-1}	0.767	0.082	<0.0001
PPL_{t-2}	0.253	0.084	0.0031
$WBPL_{t-1}$	89.872	24.008	0.0003
$BFCL_{t-1}$	-14.943	5.395	0.0066
DV_3	-13.726	1.438	<0.001
DV_4	-16.576	1.711	<0.001
R^2	0.991		

Table 3: Broiler Production, 1975-2002

Variable	Coefficients	Standard Errors	P- Values
Intercept	-12171	9929.775	0.2236
PHL_{t-1}	910.299	23.447	<0.0001
$WPBL_{t-1}$	89376	34898	0.0122
DV_3	-5564.818	1923.476	0.0048
DV_4	-11347	1921.440	<0.001
R^2	0.98		

Study results further reveal the significant and negative impacts of third quarter seasonality (July/August/September). This seasonal impact might have resulted from the costs of summer months, with resulting higher expenses for cooling of broiler houses. To meet the objectives of our study, forecasting the water demand for broilers for drinking and sanitation purposes, we selected the estimated broiler equation for forecasting of water, recursively using information from the roles of chicks and hatching flocks phases in their production.

Results of Box-Jenkins (ARIMA) time series models are presented for comparison purposes. As determined with Akaike's information criterion (AIC) and Schwarz's Bayesian information criterion (SBC), the ARIMA (1,1,1) model appears more effective in forecasting numbers of broilers in the study area than other ARIMA specifications. In our selected model, forecasted numbers of broilers (in-sample forecasting) closely tracked the observed values between 1995 and 2000, which further supports the validity of the model.

BROILER WATER DEMAND FORECASTING

So far, no specific formula exists to measure the actual amount of water use by broilers. However, the ACT/ACF study conducted by Natural Resources Conservation Service (NRCS) of Georgia estimates per day per broiler water use of 0.05000778 gallon, 0.049999489 gallon, 0.050032176 gallon, 0.049997553 gallon, and 0.04999755 gallon for the years 1992, 1995, 2000, 2005, and 2010, respectively (ACT/ACF river basin comprehensive study, 1995). The per day average broiler water use coefficient (0.050007) used by ACT/ACF study is very close to USGS estimates of 0.06 gallon per day broiler water use in Georgia. In our analysis, we assume per day broiler water use of 0.05007 as reported by NRCS for the comparison.

We first capture the effects of economic variables in broiler supply decisions. Then, we use the number of broilers forecast from the structural and time series forecasting models and the water use coefficients taken from the NRCS to forecast the water demand for broilers up to year 2007. Forecasted numbers of broilers and broiler water demand information available from the ACT/ACF comprehensive study serve as baseline information for this study. The ACT/ACF study represents a physical model; it ignores the role of any economic and institutional variables.

Table 4 shows the forecasted broiler water demand in Georgia using econometric, time series, and the physical (ACT/ACF) models. Differences in water demand between the physical, structural, and time series models have been termed as "slippage" (Tareen, 2001). Our analysis assesses this slippage by comparing the changes in total per day broiler water demand resulting from capturing the impacts of economic variables. The ACT/ACF study of NRCS assumes approximate annual broiler growth of 0.008 in the selected counties of Flint, Chattahoochee, and other ACT regions of Georgia. Assuming the same (0.008) growth rate for Georgia in coming years, the physical model forecasts 1,192, 1,201, 1,211, and 1,221 million broilers in 2004, 2005, 2006, and 2007, respectively. Given the per day broiler water use estimate of 0.05007 gallon, the physical model forecasts 59.68, 60.16, 60.64, and 61.12 million gallons per day of water demand in 2004, 2005, 2006, and 2007, respectively.

After assessing the impacts of economic variables in the broiler supply decision, our structural model yields 1,307, 1,340, 1,373, and 1,407 million broilers and 65.44, 67.09, 68.77, and 70.47 million gallons per day of water demand in 2004, 2005, 2006, and 2007, respectively. The ARIMA (1,1,1) model yields 1,364, 1,410, 1,456, and 1,503 million broilers and 68.32, 70.58, 72,89, and 75.23 million gallons per day of water demand in 2004, 2005, 2006, and 2007, respectively. We thus find that the physical model, which is based on the "educated guess" in forecasting broiler production, underestimates future water demand by approximately 15% in comparison to econometric models. This slippage arises because the physical model does not follow any statistical or econometric modeling and ignores the role of economic and institutional variables in the broiler supply behavior of farmers.

Table 4: Total Water Demand in Million Gallons per Day by Broiler Production Using Physical, Structural, and ARIMA (1, 1, 1) Forecasts

Year	Physical	Structural	ARIMA
In-Sample			
1999	57.350	58.093	57.350
2000	57.809	59.074	59.212
2001	58.271	60.630	61.791
2002	58.737	62.211	63.929
Post-Sample			
2003	59.207	63.816	66.103
2004	59.681	65.443	68.320
2005	60.158	67.093	70.581
2006	60.640	68.768	72.887
2007	61.125	70.467	75.236

CONCLUSIONS AND IMPLICATIONS

By adopting a systematic analytical approach based on the economic supply response, we forecast the broiler water demand into the future. Broiler production decisions are made in three successive stages, and in each stage growers make an economic decisions related to investment. Although the production processes and biological constraints are different for different animal types, our model serves as a demonstration model for other animal types.

All economic variables tested were significant in one or more of the production phases, reflecting the importance of incorporating economic factors. Ignoring economic variables leads to underestimation of future water demand by as much as 15%. Our study reflects no substantive difference between using structural and time series models for broiler water forecasting, fully capturing the information used in the structural models, if there is no structural change.

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