Water Demand Forecasting For Poultry Production: Structural, Time Series, and Deterministic Assessment

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A profit maximization model and an ARIMA model were developed to forecast water demand for broiler production. The forecasted numbers of broilers from structural and ARIMA model depart significantly from a USGS physical model. Analysis indicates 4% slippage in water demand forecasting related to disregarding the role of economic variables.

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 (Acharya, 1997; Jordan, 1998). Recent trends in climatic conditions and growing water demands in many sectors might threaten the sustainability of water resources, if policy makers and water managers fail to devise appropriate policies to efficiently allocate the available water. However, the task of 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). Animal agriculture (broiler, layer, turkey, beef cattle, horse, dairy cattle, and swine) requires water for drinking and cleaning purposes. Even though small in demand in comparison to water demand in many other sectors, precise estimates of future water demand for animal agriculture can play an important role at the crucial hours of water allocation decisions, given relatively fixed water availability.

Finding accurate information related to water use for animal agriculture is a difficult task in the light of the dearth of past research and systematic records of water use data. Except for the aggregate animal water use data published by the United States Geological Survey (USGS), there exists very little information about animal water use in the United States. Unfortunately, estimates of USGS water demand is based on a static physical model, where future water demand is a function of temperature, daylight, and physiological conditions of animals. The USGS water forecasting model carries limitations of other similar water models by failing to capture the animal production behaviors of farmers, which change with fluctuations in economic and institutional variables.

Indeed, the production of animals by farmers is an economic decision that is 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 government programs. A sound supply response model and rigorous econometric analysis is 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 by incorporating economic variables. As a result, this represents a significant departure from previous studies in the same areas that have ignored changes in animal water demand in response to changes in prices, policies, and government support programs.

This study adopts a systematic analytical approach based on economic principles (supply response functions) to forecast the number of animals in future years under the influence of changing economic variables. Forecasting water demand for all animal types, such as broilers, layers, turkeys, beef cattle, horses, dairy cattle, and swine, is beyond the scope of this paper. Therefore, we selected broiler production in Georgia for future water demand modeling purposes. Although the production processes and biological constraints are different for different animal types, our model serves as a representative model for other animal types if researchers incorporate the production stages of other animal types in a given model.

Theoretical Model Development

For theoretical model development, we consider a competitive firm where production function can be decomposed into N production stages. For example, in swine production, the breeding herd represents the first stage of production function. And sow slaughter, pig crop, and barrow or gilt slaughter comprise subsequent stages of production. Even though the different stages of production are biologically or functionally related to each other, we can decompose and analyze the swine production process in sequence of production phases separately. At each stage, the owner makes a decision about selected variable input and some form of capital is transformed into a different form of capital (Jarvis, 1974). Conceptually, we can represent this type of production function as (Chavas and Johnson, 1982):

$Y_k = f_k(Y_{k-1}, X_k)$, ----------------------(1)

Where k = 1,2…n;

Y_k = vector of capital stock at stage t

Y_{k-1} = lagged vector of capital stock

X_k = Vector of variable inputs used in the t^{th} production stage

Here, vector of variable inputs X_k changes the capital Y_{k-1} in to different form of capital Y_k. In the case of poultry production, Y_1, Y_2 ,and Y_3 represent the primary breeder, the grow out flock, and broiler production, respectively. Vector of variable inputs like feeds, medicine, and other nutritional supplements change poultry production from one stage of production to another stage of production. In each stage, broiler growers (integrators) make an economic decision related to investment, and some form of capital is transformed into a different form of capital. Considering Y_t as a scalar and capital stock as a single variable, we develop a profit function as:

$$\Pi = PY_n + \sum_{i=1}^{n-1} S_kY_k - \sum_{i=1}^{n-1} R_kX_k - R_0Y_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

P = output price

Y_n = final output

S = salvage value of the capital stock Y_k

R_k = price of the input X_k,

R_0 = purchase price of Y_0.

Ignoring salvage value and considering the constrains of production technology (equation 1) and profit maximization

(Equation 2),

$$\Pi = PY_n - \sum_{i=1}^{n-1} R_kX_k - R_0Y_0 \quad \text{s.t.} \quad Y_k = f_k(Y_{k-1}, X_k),$$

Now, our optimality condition as indicated by asterisk would be:

$X^*_k = g_k(P, R_k, Y^*_{k-1})$, where k = 1,…,n and --(3)

$Y^*_k = f_k\ (Y^*_{k-1}, X^*_k)$

$= h_k(Y^*_{k-1}, p, R_k)$, …………………………………………………………… .(4)

where k = 1,…..,n, R_k = (r_k,……………..r_n) represents vector of input prices.

Here, Equation 4 clearly shows economic decisions made at earlier stages define the optimality condition at each stage of broiler production. Equation 4 represents a static optimality condition and introducing a time variable at each stage of production allows us to examine the dynamics of broiler production system. However, in many cases underlying production technology alters or strongly influenced the time lag separating two successive stages of production. Suppose that after a delay of 'j' time periods, it takes 'i' time periods to transform the capital stock Y_{k-1} in to Y_k , then Equation 4 can be express as:

$Y_{kt} = f_k (Y_{k,t-j}, Yk_{, t-j-1},……,Y_{k,t-j-I}, P_t, R_{kt,})$, ---(5)

where P, and R, respectively, show the output price and input prices expected by the decision maker at time t. Generally, the time lag between two stages in Equation 5 is mostly defined by the underlying production technology. However, there are instances in broiler production process when production or economic decisions made by integrators influence the lag between two successive stages. It is mostly true when sudden changes in price of out put or input occurs. For example, increase in short-run profitability of eggs might 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 chick, fee, medication, and other technical support to growers. The integrator also co-ordinates 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 (personal communication with Dr. Mckissick). Placement refers to the introduction of chicks into the broiler production or number of chicks placed into hatchery supply flocks. Hatching refers to the hatching of eggs from the hatchery supply flock. After hatching, chicks enter into broiler production. In the broiler production system, ‘placement’, ‘hatching’, and ‘production’ follow a sequence of production.

Understanding of 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, which generally lasts for 10 months in broiler type chickens. After hatching, approximately eight weeks is needed to produce 3.8 lbs live weight broiler (72% dressing). These underlying time gaps between the different stages of broiler production and Equation 5 offer an insight to develop a dynamic broiler supply response function.

A representative broiler production stages comprise of:

PLACEMENT

$B1 = \beta_0 + \beta_1 PBL_2 + \beta_2 FCL_2 + \beta_3 B1L_4 + \beta_4 DV_2 + \beta_5 DV_3 + \beta_6 DV_4 + \beta_7 TT$---------------(6)

HATCHING

$B2 = \beta_0 + \beta_1 B1L_1 + \beta_2 B1L_2 + \beta_3 B1L_3 + \beta_4 PBL_1 + \beta_5 FCL_1 + \beta_6 DV_2 + \beta_7 DV_3 + \beta_8 DV_4$

$+\beta_9 TT$---------(7)

PRODUCTION

$B3 = \beta_0 + \beta_1 B2L_1 + \beta_2 PBL_1 + \beta_3 FCL_1 + \beta_4 DV_2 + \beta_5 DV_3 + \beta_6 DV_4 + \beta_7 TT$-------------(8)

PB = wholesale price of broilers

DV_i = dummy variable for the ith quarter

TT = time trend

FC = feed cost

B1 = broiler type placements in hatchery supply flocks

B2 = hatching of broiler type chicks in commercial hatcheries

B3 = broiler production

Time Series Forecasting Model

In order to make comparative forecasting of broiler supply response and thereby broiler water demand with econometric and physical models, 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 written as

$\phi(B)\,\Delta^d y_t = \delta + \phi\,(B)\epsilon_t$

where y_t represents number of broiler in time t,ϵ_t are random normal error terms with mean zero and variance σ^2_t and Δ^d denotes differencing i.e.)$\Delta y_t = y_t - y_{t-1}$,

$\phi(B) = 1 - \phi_1(B) - \phi_2(B)^2 - ....- \phi_p(B)^p$,

and

$\phi(B) = 1 - \phi_1(B) - \phi_2(B)^2 - .... - \phi_q(B)^q$

Where B represents the backward shift operator such that $B^n{}_{et} = \epsilon_{t-n}$ In ARIMA model, the supply response is modeled dependent on past observation of itself. Future output price and number of broiler were estimated by using Box-Jenkins (ARIMA) time series models.

Data

Our study covers the lower Flint (Baker, Calhoun, Decatur, Dougherty, Early, Grady, Lee, Miller, Mitchell, Seminole, and Worth), Middle Flint (Crawford, Crisp, Dooly, Macon, Marion, Randolph, Schley, Sumter, Taylor, Terrell, and Webster), and Upper Flint (Clayton, Coweta, Fayette, Lamar, Meriwether, Pike, Spalding, Talbot, and Upson) regions of Georgia. Basically, we select the study area to make our study results comparable with the findings of the Alabama-Coosa-Tallaposa (ACT) /Apalachicola-Chattahooche-Flint (ACF) comprehensive study, a representative physical model of the same study area. In order to carry out the objectives of the study, quarterly data of the1970-2000 hatching flock, broiler chick placement, and final broiler numbers of selected counties of Georgia was collected from National Agricultural Statistics Services (NASS) of United States Department of Agriculture (USDA) and Georgia Agricultural Facts. Information about the wholesale price of broiler and feed costs were collected from Economic Research Service (ERS) of United States Department of Agriculture (USDA) publications. Realizing the nature of underlying technology of broiler production, we consider a quarterly observation while analyzing broiler supply function. In our analysis, lagged observed wholesale output (broiler) price is considered as expected price for output. 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. Futures feed costs and output prices were estimated by using Box-Jenkins (ARIMA) specification. Water use coefficients for broiler were collected from the USGS.

Results and Discussions

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 adjusted R^2 of 0.98 (Table 1). Placement in the hatchery supply flock (B1) represents the first stage of broiler production. In our analysis of placement, elasticities of output price and feed costs were statistically significant at 1 % level and yield expected signs. Analysis of output price elasticity shows that one percent increase in the output price increases the introduction of chicks into the production process (placement) by 0.14 percent. Meanwhile, feed cost elasticity of -0.0086 shows a decrease of 0.86 percent of chicks in the production process for every 100 percent increase in the feed cost of chicks. Study results reveal a statistically insignificant role of seasonality. However, there was a statitistically significant impact of trend variable.

In the hatching equation, Equation (7) table 2, feed cost and output price are lagged one quarter while placement (chicks) is lagged one, two, and three quarters. In hatching of eggs from the hatchery supply flock, placement lag (quarter three) is statistically significant with elasticities of 2.4, showing that one percent increase in placement in the third quarter increases the hatching by 2.4 percent. As expected, output price had positive sign and statistically significant at 1% level of significance. Feed cost elasticity in hatching stage production was –0.38. It shows a decrease of 0.38% of hatching for every one percent increase in the feed cost. With the statistically insignificant coefficients for seasonal dummies and time variable, the study concludes no impacts of season and time variables in this stage of broiler production.

Hatched chicks are generally fed for approximately eight weeks to get a marketable broiler weight. In the broiler production Equation (8) table 3, feed cost (FC) and broiler wholesale price (PB) are lagged one quarter. Estimated elasticities for price of wholesale broiler and feed cost are statistically significant and have the expected sign. Output price elasticity of 0.21 an increase of 2.1% increase in broiler production for every 10% increase in the output price. Meanwhile, every 1% increase in the cost of feed decreases the broiler production by 0.22 percent. These results are consistent with the finding of many researchers (Aadland and Bailey, 2001;Freebairn and Rausser, 1975; Bhati, 1987; Mbaga, 2000). Study results further reveal the statistically significant and negative impacts of third quarter (June, July, August). It might have resulted from the summer months and resulting higher expenses for cooling of broiler houses. Our study basically aims to forecast the water demand for broiler for drinking and sanitation purposes. In order to meet the objective of study, we selected estimated broiler equation for econometric forecasting of water, ignoring the role of chicks and hatching flocks.

Results of Box-Jenkins (ARIMA) time series models are presented in Table 4 for comparison purposes. As determined with Akaike's information criterion (AIC) and Schwarz's Bayesian information criterion (SBC), the ARIMA (2,1,0) model seems more effective in forecasting the number of broilers in the study area than other ARIMA specifications. Study results show AIC and SBC value of 2399 and 2405, respectively, for broiler production. Other ARIMA specifications like ARIMA (1,1,1), ARIMA (2,1,1) and ARIMA (0,1,2) also have AIC and BIC values very close to the selected model. However, forecasted values from these ARIMA models deviate drastically from the actual observed number of broilers in the study area. In our selected model, the forecasted number of broilers closely traced observed values between 1995 and 2000, which further supports the validity of the model.

Broiler Water Demand Forecasting

So far, there exists no specific formula to measure the actual amount of water use by broilers. However, using the educated guess of animal experts; ACT/ACF study estimates per day per broiler water use of 0.05000778 gallon, 0.049999489 gallons, 0.050032176 gallons, 0.049997553 gallons, and 0.04999755 gallons for the year 1992, 1995, 2000, 2005, and 2010 respectively (ACT/ACF river basic comprehensive study, 1995). In our analysis, we first capture the effects of economic variables in broiler supply decisions. Then, we use the number of broilers available from the structural and time series forecasting models and the water use coefficients available from the ACT/ACF study to forecast the amount of water demand for broilers up to year 2010. In this study, forecasted number of broilers and amount of water from ACT/ACF comprehensive study serve as baseline information. ACT/ACF study represents a physical model as it ignores the role of any economic and institutional variables while forecasting the number of broiler and thereby the level of broiler water demand.

Tables 5 and 6 show the forecasted number of broilers and corresponding water demand in our study area. Differences in water demand between the physical, structural, and time series models have been termed as “slippage” (Tarren, 2001). Our analysis assesses this slippage by comparing the reduction in estimates of water demand resulting from capturing the impacts of economic variables. Using a physical model, the Natural Resources Conservation Service (NRCS) forecasts 503,476, 517,351, and 531,226 broilers (thousands) and 25.19, 25.86, and 26.56 million of gallons of water (MGD) per day respectively. NRCS reports that of all the animals inventoried for the ACT/ACF comprehensive study, broilers use the most water annually. The 531 million broilers in 2010 represent more than double the number of broilers in the study area. More than 82 percent of the broilers are in the Upper Chattahooche and Upper ACT planning areas.

After assessing the impacts of economic variable in broiler supply decision by integrators, our study results show 495,981 and 509,179 broilers (thousands) and 24.83 and 25.49 MGD of water demand for broilers in the selected counties of Georgia in

2005 and 2010, respectively, or 4% less than the physical model. Analysis of future broiler number by using Box-Jenkins approach shows 501,224 and 517, 953 broilers (thousands) and 25.05 and 25.89 MGD of water in 2005 and 2010 respectively. Based on the findings of our analysis, we conclude the physical model, which is based on the educated guess in forecasting broiler production, over-estimates the future water demand. It arises because the physical model does not follow any statistical or econometric modeling and ignores the role of economic and institutional variables, which in most cases defines the broiler supply behaviors of farmers. The analysis also shows no substantive difference between the structural and time series forecast models.

Conclusions

This study adopts a systematic analytical approach based on economic principle (supply response functions) to forecast the number of broilers in future years under the influence of changing economic variables. We basically adopt a profit-maximization framework, given the technology constrains. In our broiler profit maximization model, broiler production decisions are made in three successive stages, namely primary breeding flock, hatchery flock, and finishing broiler production. In each stage, broiler growers make an economic decision related to investment, and some form of capital is changed into a different form of capital.

In our analysis, all economic variables were statistically significant reflecting the importance of incorporating economic variables while forecasting number of broilers and thereby future broiler water demand. Analysis further shows that ignoring economic variables leads to overestimation of future water demand. Study also reflects no substantive difference between using structural and time series models for broiler water forecasting purposes.

Table 1: Parameter estimates of Placement and Elasticities at Means, 1970-2001

Variable	Coefficients	Standard Error	P- Value	Elasticity
Intercept	236.591	157.050	0.136	
PBL_2	7.935	2.330	0.001	0.14
FCL_2	-0.413	0.0385	0.001	-0.0086
$B1L_4$	0.730	0.055	2E-21	0.71
DV_2	-0.561	15.916	0.972	
DV_3	-15.141	16.143	0.351	
DV_4	-6.723	15.963	0.675	
TT	3.986	1.053		
R Square	0.982936			
Adjusted R Square	0.981364			

Table 2: Parameter estimates of Broiler Hatching Flock and Elasticities at Means, 1970-2001

Variable	Coefficients	Standard Error	P- Value	Elasticity
Intercept	1505.68	845.172	0.0791	
$B1L_1$	-0.426	0.951	0.655	-0.33
$B1L_2$	-0.089	1.272	0.944	-0.068
$B1L_3$	3.127	0.926	0.001	2.4
PBL_1	-25.878	12.213	0.037	-0.38
FCL_1	-7.254	1.987	0.000	-1.19
DV_2	115.960	105.231	0.274	
DV_3	-40.137	98.338	0.684	
DV_4	-25.045	109.861	0.820	
TT	-6.402	6.342	0.316	
R Square	0.841			
Adjusted R Square	0.820			

Table 3: Parameter estimates of Broiler Production and Elasticities at Means, 1970-2001

Variable	Coefficients	Standard Error	P- Value	Elasticity
Intercept	31926.31	23164.57	0.172227	
$B2L_1$	9.703806	2.214024	3.76E-05	0.09
PBL_1	1566.35	354.4765	3.29E-05	0.21
FCL_1	-144.5474	58.63114	0.015974	-0.22
DV_2	-907.04	2362.291	0.70209	
DV_3	-6261.86	2352.665	0.009509	
DV_4	-2009.04	2350.916	0.395508	
TT	1753.967	115.8479	1.65E-24	
R Square	0.983959			
Adjusted R Square	0.982462			

Table 4: Physical, Structural and Selected ARIMA Models Forecast of Number of Broiler (thousands) 1995 to 2010.

Year	Physical	Econometric	ARIMA (2,1,0)	ARIMA (1,1,1)	ARIMA (2,1,1)	ARIMA (1,1,2)	ARIMA (0,1,2)
1995	489605	471,239	478,632	489,232	491,367	491,691	516,694
1996		476,591	482,021	522,900	522,244	523,120	562,180
1997		482,151	482,312	566,939	567,106	566,744	571,128
1998		482,216	482,631	573,266	575,606	575,755	570,143
1999		482,691	489,251	577,808	575,944	575,830	592,735
2000	503476	482,792	495,629	596,220	594,158	592,383	586,606
2001		483,215	496,512	583,904	585,068	584,314	590,437
2002		483,991	497,825	590,301	589,247	588,316	599,044
2003		491,002	498,123	597,059	595,670	593,715	607,651
2004		491,221	499,517	604,106	602,094	600,055	616,258
2005	517351	495,981	501,224	611,383	609,151	607,026	624,865
2006		495,991	502,316	618,845	616,441	614,422	633,473
2007		496,213	502,984	626,454	623,994	622,103	642,080
2008		496,369	514,523	634,180	631,710	629,977	650,687
2009		500,121	516,469	642,001	639,560	637,979	659,294
2010	531226	501,179	517,953	649,897	647,505	646,069	658,921
A/C			2399	2400	2401	2400	2404
SBC			2405	2407	2409	2409	2410

Table 5: Total Number of Broiler (thousands) using Physical, Structural, and ARIMA (2,1,0) Forecasts

Year	Physical Model	Econometric Model	ARIMA (2,1,0)
1992	475,726	455,963	462,329
1995	489,605	471,239	478,632
2000	503,476	482,792	495,620
2005	517,351	495,981	501,224
2010	531,226	509,179	517,953

Table 6: Total Water Demand in Million Gallons Per Day by Broiler Production Using Physical, Structural, and ARIMA (2,1, 0) Forecasts

Year	Physical Model	Econometric Model	ARIMA (2,1,0)
1992	23.79	22.83	23.12
1995	24.48	23.51	23.93
2000	25.19	24.18	24.79
2005	25.86	24.83	25.05
2010	26.56	25.49	25.89

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