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WATER RESOURCES PLANNING FOR BROILER PRODUCTION: ECONOMETRIC AND TIME SERIES ANALYSIS

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ABSTRACT

A profit maximization model and an ARIMA model were developed to assess and plan for future water demand need in broiler production. In planning the future water demand, successive stages of broiler production decisions were taken into consideration. The forecasted numbers of broilers from profit maximizing and ARIMA models depart significantly from the commonly used United States Geological Survey physical model. Analysis indicates 15% slippage in water demand forecasting when the role of economic variables is not considered. We also found 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 [1, 2]. 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 the lack of information about present and future water demand by different sectors of water use, including animal agriculture [3]. 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 in water allocation decisions, given relatively fixed water availability.

Finding accurate information related to water use for animal agriculture is a difficult task, in light of the scarcity of past research and systematic records of water use data. Except for the aggregate animal water use data published by the United States Geological Society (USGS), there exists very little information about animal water use in the United States. Unfortunately, estimates of USGS water demand are 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 similar to other past water models by failing to capture the animal production behavior of farmers, which changes with changes in economic and institutional variables.

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 that have ignored changes in animal water demand in response to changes in prices, policies, and government programs.

This study adopts a systematic analytical approach based on the economic principles of supply response functions to forecast the number of animals in future years under the influence of changing economic variables. We first select 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 incorporation of the production stages of other animal types is modeled.

THEORETICAL MODEL DEVELOPMENT

For theoretical 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 [4]. Conceptually, we can represent this type of production function as (following Chavas and Johnson [5]):

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

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, medicine, and other nutritional supplements, changes poultry forms 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:

$$\Pi = PY_n + \sum_{k=1}^{n-1} S_k Y_k - \sum_{k=1}^{n-1} R_k X_k - R_0 Y_0 \tag{2}$$

where P = output price, Y_n = final output, S = salvage value of the capital stock Y_k, R_k = price of the input X_k, and R_0 = purchase price of Y_0.

Ignoring salvage value and considering the constraints of the production technology (equation 1) and profit maximization in (equation 2), our profit function can be restated as

$$E(\Pi) = PY_n - \sum_{k=1}^{n-1} R_k X_k - R_0 Y_0 \;\; \text{s.t. } Y_k = f_k(Y_{k-1}, X_k). \tag{2a}$$

Thus, our optimality condition, as indicated by asterisk, would then be:

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

$$Y^*_k = f_k(Y^*_{k-1}, X^*_k) = h_k(Y^*_{k-1}, p, R_k). \tag{4}$$

Here, k = 1,....., n, and $R_k = (r_k,...,r_n)$ represents a vector of input prices.

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 optimally condition, and introducing time variables at each stage of production allows us to examine the dynamics of the broiler production system. However, in many cases, underlying production technology alters or strongly influences the time lag separating two successive stages of production. Suppose that if, after a delay of "j" time periods, it takes "I" time periods to transform the capital stock Y_{k-1} into Y_k, then equation (4) can be expressed as

$$Y^*_{kt} = f_k\,(Y_{k,\,t-j}, Y_{k,\,t-j-I}, \ldots\ldots, Y_{k,t-j-i}, P_t, R_{kt}). \tag{4a}$$

Here, P and R show the output price and input prices expected by the decision maker at time t, respectively. Generally, the time lag between two stages in equation (4a) is mostly defined by the underlying production technology. However, there are instances in the broiler production process where production or economic decisions made by integrators influence a change in the lag between two successive stages. This is generally true 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

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. The integrators also co-ordinate processing and marketing activities. Given the current nature of broiler production, the broiler production decision in the Southeast United States can be examined in three successive stages, namely placement, hatching, and broiler production [6]. Placement refers to the introduction of chicks into the broiler production or the 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.

Understanding the underlying technology of the 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) live weight broiler (72% dressing). These underlying time gaps between the different stages of broiler production and equation (4a) offer an insight to develop a dynamic broiler supply response function. A representative broiler-production process can be modeled using the following three stages:

Stage 1: Broiler-breeder placement (BBP)

$$BBP_t = \alpha_0 + \alpha_1\,BBP_{t-i} + \alpha_2\,WBP_t + \alpha_3\,WBP_{t-i} + \alpha_4\,BFC_t + \alpha_5\,BFC_{t-i} + \alpha_6\,T67 + \alpha_7\,DV_2 + \alpha_8\,DV_3 + \alpha_9\,DV_4 + u_t \tag{5}$$

Stage 2: Hatching (BH)

$$BH_t = \beta_0 + \beta_1\ PBP_{t-i} + \beta_2\ WBP_t + \beta_3\ WBP_{t-i} + \beta_4\ BFC_t + \beta_5\ BFC_{t-i} + \beta_6\ T67 + \beta_7\ DV_2 + \beta_8\ DV_3 + \beta_9\ DV_4 + \xi_t \quad (6)$$

Stage 3: Broiler production (BRP)

$$BRP_t = \gamma_0 + \gamma_1\ PBH_{t-i} + \gamma_2\ WBP_{t-i} + \gamma_3\ BFC_t + \gamma_4\ BFC_{t-i} + \gamma_5\ T67 + \gamma_6\ T67 + \gamma_7\ DV_3 + \gamma_8\ DV_4 + \nu_t \quad (7)$$

Here,

$\alpha_0, \beta_0, \gamma_0$ = intercepts;
BBP_t = broiler placement in current quarter in millions;
BBP_{t-i} = broiler placement in lagged i^{th} (i = 1, 2, 3, 4) quarters in millions;
WBP_t = 12-city composite wholesale price (ready-to-cook) in the current quarter, deflated by CPI (1982-84 = 100) in cents per pound;
WBP_{t-i} = 12-city composite wholesale price (ready-to-cook) in lagged i^{th} (i = 1, 2, 3, 4) quarters, deflated by CPI (1982-84 = 100) in cents per pound;
BFC_t = broiler feed prices paid by farmers in current quarter deflated by CPI (1982-84 = 100) in dollars per ton;
BFC_{t-i} = broiler feed prices paid by farmers in lagged i^{th} (i = 1, 2, 3, 4) quarters deflated by CPI (1982-84 = 100) in dollar per ton;
T_{67} = time trend variable, year 1967 = 1;
DV_2, DV_3, DV_4 = quarterly seasonal binary variables in quarters 2, 3, and 4, respectively;
BH_t = broiler type chick hatched by commercial hatcheries in Georgia in current quarter in millions;
PBP_{t-i} = predicted broiler-breeder placement in lagged i^{th} (i = 1, 2, 3, 4) quarters in millions in Georgia;
BRP_t = quarterly broiler slaughtered under federal inspection in thousands;
PBH_{t-i} = predicted broiler-breeder hatching in lagged i^{th} (i = 1, 2, 3, 4) quarters in millions; and
ν_t, ξ_t, u_t = stochastic error terms.

TIME SERIES FORECASTING MODEL

To 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 written:

$$\phi(B)\ \Delta^d y_t = \delta + \phi\ (B)\varepsilon_t \quad (8a)$$

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

$$\phi(B) = 1 - \phi_1(B) - \phi_2(B)^2 - \ldots\ldots - \phi_p(B)^p, \text{ and} \tag{8b}$$

$$\phi(B) = 1 - \phi_1(B) - \phi_2(B)^2 - \ldots\ldots\ldots - \phi_q(B)^q \tag{8c}$$

where B represents the backward shift operator such that $B^n\varepsilon_t = \varepsilon_{t-n}$. 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.

DATA

To carry out the objectives of the study, quarterly data of 1967-2002 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. Information about the wholesale price of broiler and feed costs was collected from the Economic Research Service (ERS) of USDA publications. The wholesale price of broilers and broiler feed costs were deflated by using consumer price index (all urban consumer, U.S. city) average (1982-84 = 100).

Realizing the nature of the underlying technology of broiler production, we consider a quarterly observation period when analyzing the broiler supply function. 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 [7]. 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.

RESULTS AND DISCUSSIONS

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. In order to achieve the goals of study, 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.

Ordinary least squares (OLS) regression analysis is based on several statistical assumptions, including independence of the stochastic errors term. However, with the use of time series data, the residuals might correlate over time, violating the assumptions of OLS. The problem of autocorrelation especially arises where one or more lagged values of the dependent variable serve as explanatory variables. The OLS estimates of an autoregressive model are generally biased and inconsistent, leading to incorrect statistical test results and/or false inferences. 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. In statistical terms, it is called autoregressive error correction or serial correlation correction. 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 forward selection procedure starts with the null (b_0) model, and then adds the variable with the lowest *P*-value (highly significant). After adding the first variable, the next significant variable is similarly chosen (with the first already entered into the model). The process continues until none of the variables not already entered meets the entry-level selection value (i.e., alpha = 0.10) in our model. The backward selection procedure starts with the full K variables model and deletes the variable with the highest standard error until all p variables remaining are significant at the chosen selection level (alpha = 0.10). The stepwise procedure combines both backward selection and forward selection to propose the chosen model.

Table 1. Parameter Estimates of Broiler Chick Placement and Elasticities at Means, 1967-2002

Variable	Coefficients	Standard errors	*P*-values	Elasticity
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	0.061
T	0.3514	0.0675	< 0.0001	
R-square	0.9928			
Total *R*-square	0.9928			
D-W test	5.6347			

Table 2. Parameter Estimates of Broiler Hatching Flock and Elasticities at Means, 1967-2002

Variable	Coefficients	Standard errors	*P*-values	Elasticities
Intercept	1.761	0.961	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	0.729
$BFCL_{t-1}$	–14.943	5.395	0.0066	0.0416
DV_3	–13.726	1.438	< 0.001	
DV_4	–16.576	1.711	< 0.001	
R-square	0.9913			
D-W test	0.700			

Table 3. Parameter Estimates of Broiler Production and Elasticities at Means, 1975-2002

Variable	Coefficients	Standard errors	*P*-values	Elasticity
Intercept	–12171	9929.775	0.2236	
PHL_{t-1}	910.299	23.447	< 0.0001	
$WPBL_{t-1}$	89376	34898	0.0122	0.078
DV_3	–5564.818	1923.476	0.0048	
DV_4	–11347	1921.440	< 0.001	
R-square	0.98			
D-W test	0.833			
1st order				
Autocorrelation	0.579			

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 (BBP_t) represents the first stage of broiler production. Only variables significant at the 90% confidence level are presented in Table l. The estimated coefficients of chick placement and wholesale broiler price in the lag structure yield positive signs, findings consistent with the study of Chavas and Johnson [5]. Although insignificant, the estimated coefficients of the broiler feed price had negative signs. In our analysis, elasticity of one-quarter lag broiler wholesale price was significant at the 10% level. Analysis shows that a 1% 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 statistically significant at 90% confidence level. As expected, wholesale broiler price had a positive sign and statistically significant. Analysis of elasticity shows an increase in 1% of wholesale broiler price increases the expected broiler type chick hatching by commercial hatcheries by 0.729%. Feed cost elasticity in hatching stage of production was –0.041 and statistically significant. This 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. At the 10% level of significance, 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. Contrary to our expectation, broiler feed costs fail to show significant impacts on broiler production. This result was not consistent with the finding of other researchers [8-11], 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. 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 seems more effective in forecasting number of broiler in the study area than other

ARIMA specifications. Other ARIMA specifications, such as ARIMA (2,1,0), 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 AR1MA models deviate drastically from the actual observed number of broilers in the study area. 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, there exists no specific formula to measure the actual amount of water use by broilers. However, the ACT/ACF study conducted by United States Department of Agriculture, Natural Resources Conservation Service 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 [12]. 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 purposes.

In our study, 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 NRCS to forecast the amount of water demand for broiler 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, as it ignores the role of any economic and institutional variables while forecasting the number of broiler and thereby the levels of broiler water demand.

Tables 4 and 5 show the forecasted number of broilers and corresponding broiler water demand in Georgia using econometric, time series, and the physical (ACT/ACF) model. Differences in water demand between the physical, structural, and time series models have been termed as "slippage" [13]. Our analysis assesses this slippage by comparing the changes in total per day broiler water demand resulting from capturing the impacts of economic variables. 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.

Table 4. Total Number of Broilers (millions) in Georgia Using Physical, Structural, and ARIMA (1, 1, 1) Forecasts

Year	ARIMA	Econometric model	Physical model
1999	1,145	1,160	1,145
2000	1,183	1,180	1,155
2001	1,234	1,211	1,164
2002	1,277	1,242	1,173
2003	1,320	1,275	1,182
2004	1,364	1,307	1,192
2005	1,410	1,340	1,201
2006	1,456	1,373	1,211
2007	1,503	1,407	1,221

Table 5. Total Water Demand in Million Gallons per Day by Broiler Production Using Physical, Structural, and ARIMA (1, 1, 1) Forecasts

Year	ARIMA	Econometric model	Physical model
1999	57.350	58.093	57.350
2000	59.212	59.074	57.809
2001	61.791	60.630	58.271
2002	63.929	62.211	58.737
Out of sample			
2003	66.103	63.816	59.207
2004	68.320	65.443	59.681
2005	70.581	67.093	60.158
2006	72.887	68.768	60.640
2007	75.236	70.467	61.125

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. Similar analysis using the time series 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. Based on our findings, we conclude that the physical model, which is based on the "educated guess" in forecasting broiler production, underestimates future water demand by approximately 11% 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, which in most cases define the broiler supply behavior of farmers. The analysis also shows no substantive differences between the structural and time series forecasts models.

CONCLUSIONS

This study adopts a systematic analytical approach based on the economic principles of supply response functions to forecast the number of broilers in future years under the influence of changing economic variables. We adopt a profit-maximization framework, given the technology constraints. In our broiler profit maximization model, broiler production decisions are made in three successive stages, namely primary broiler breeding flock, hatchery flock, and finishing broiler production. In each stage, broiler producers 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 tested were significant in one or more of the broiler production phases, reflecting the importance of incorporating economic variables while forecasting the number of broilers and thereby future broiler water demand. Analysis further shows that ignoring economic variables leads to underestimation of future water demand by as much as 15%. Our study also reflects no substantive difference between using structural and time series models for broiler water forecasting purposes, indicating that an appropriate lag structure can fully capture the information used in structural models, assuming no structural change.

REFERENCES

1. R. Acharya, *Economics Simulation and Optimization of Irrigation Water in Humid Regions,* Ph.D. dissertation, Department of Agricultural Economics and Rural Sociology, Auburn University, 1997.
2. J. L. Jordan, *An Introduction to Water: Economic Concepts, Water Supply, and Water Use,* Department of Agricutural and Applied Economics, The University of Georgia, Faculty Series 98-13, 1998.
3. U. Hatch, K. Paudel, J. Cruise, M. Lamb, M. Masters, A. Limaye, and D. Perkey, *Hydrologic-Economic Evaluation of Use and Value of Irrigation Water,* proceedings of the American Water Resources Association, Utah, 2001.
4. L. S. Jarvis, Cattle as Capital Goods and Ranchers as Portfolio Mangers: An Application to the Argentine Cattle Sector, *Journal of Political Economy, 82,* pp. 480-520, 1974.

5. J. P. Chavas and S. R. Johnson, Supply Dynamics: The Case of US Broilers and Turkeys, *American Journal of Agricultural Economics, 64,* pp. 558-564, 1982.
6. J. McKissick, Personal communication, Department of Agricultural and Applied Economics, The University of Georgia, May 2003.
7. J. F. Muth, Rational Expectations and the Theory of Price Movements, *Econometrica, 29,* pp. 315-335, 1961.
8. D. Aadland and D. Bailey, Short-Run Supply Responses in the US Beef-Cattle Industry, *American Journal of Agricultural Economics, 83,* pp. 826-839, 2001.
9. J. W. Freebairn and G. C. Rausser, Effects of Changes in the Level of US Beef Imports, *American Journal of Agricultural Economics, 57,* pp. 676-688, 1975.
10. U.N. Bhati, Supply and Demand Responses for Poultry Meat in Australia, *Australian Journal of Agricultural Economics, 31,* pp. 256-265, 1987.
11. M. D. Mbaga, *A Dynamic Adjustment Models of the Alberta Beef Industry Under Risk and Uncertainty,* Ph.D. dissertation, Department of Agricultural Economics and Farm Management, The University of Manitoba, 2000.
12. USDA/NRCS (United States Department of Agriculture–Natural Resource Conservation Services), *ACT/ACF Rivers Basins Comprehensive Study: Agricultural Water Demand,* 1995.
13. I. Tareen, *Forecasting Irrigation Water Demand: An Application to the Flint River Basin,* Ph.D. dissertation, Department of Agricultural and Applied Economics, The University of Georgia, 2001.

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