Alternative Methods of Forecasting Agricultural Water Demand: A Case Study on the Flint River Basin in Georgia

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Abstract

Future agricultural water demands are determined by employing forecasts from irrigated crop acreage models. Forecasts of prices and yields, and variances and covariances of crop returns are employed for forecasting crop acreage. Results provide insights into the value of rational expectations in forecasting agricultural water demand.

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As population pressures place increasing strain on our limited supply of natural resources, mechanisms designed for allocating this supply among competing demands are required. This limited supply is particularly acute in our demand for water. In a USDA, Natural Resources Conservation Service (USDA, NRCS) study, greater pressure on water resources in the tri-state area of Alabama, Florida and Georgia is the root cause of ensuing water negotiations and law suits among these states. According to this study, agriculture within Georgia is the major consumptive water user.

The recent drought in the Southeast has resulted in greater uncertainty in agricultural yields. This uncertainty has accentuated the demand for agricultural water use (irrigation) in the face of restricted supply. Attempting to aid in allocating water within the tri-state area the Georgia Legislature in February 2001 passed the Flint River Drought Protection Act (FRDPA). A component of this act was to hold an auction among southwest Georgia agricultural producers, with water permits, for the withdrawal of acreage from irrigation using perennial surface water sources in 2001. On March 17, 2001, bids to suspend irrigation were submitted. After five rounds of auction, Georgia's Environmental Protection Division (EPD) declared the auction closed with the EPD accepting offers on 209 of the 347 water permits registered at an average offer price of $135.70 per acre. This auction withdrew slightly more than 33,000 acres of farmland from irrigation.

This estimate of water savings from reduced crop acreage is obtained using the Blaney-Criddle (BC) formula (USDA, SCSED). Blaney and Criddle found the amount of water consumptively used by crops during their normal growing season was closely correlated with mean monthly temperatures and daylight hours. They developed coefficients that can be used to convert consumptive use data for a given area to other areas for which only climatological data are available. The net amount of irrigation water necessary to satisfy consumptive use is found by subtracting the effective precipitation from the consumptive water requirement during the growing or irrigation season.

The actual reduction in water use from reduced irrigated acreage is driven by changes in the distribution of crops producers choose to irrigate. This change in crop distribution resulting from reduced irrigation acreage is determined by the expected profitability of competing crops. Considering the possible economic substitution and expansion effects associated with changes in agricultural prices, will accurately predict this change in crop distribution. Conventional physical models do not consider these substitution and expansion effects in determining agricultural water demand. The difference in a physical model calculation of change in water demand and the actual change is called slippage. In contrast, an econometric model based on a theoretical model addressing economic substitution and expansion effects will consider these effects, and thus will directly address this slippage problem. The research underlying this paper identifies the presence of slippage and pitfalls associated with not considering economic substitution and expansion effects in measuring changes in water demand. Analysis of the FRDPA indicates a slippage of 18% occurs when disregarding the role of economic determinants.

Theoretical Model

The demand for irrigation water is a derived demand evolving from the value of agricultural products produced. Static and deterministic empirical models of water demand indicate adoption of modern irrigation technologies depends on price of water, labor, output level, output prices, soil slope, water holding capacity and climate (Caswell and Zilberman; Lichtenberg; Nieswiadomy; Negri and Brooks; Schaible *et al.*).

The deterministic models are effective in assessing seasonal water demand and irrigation technology choices by risk neutral producers. However, given risk in yields and prices, there is uncertainty involved with the profits of an enterprise. Irrigation is an example of a risk-reducing technology. The decision to irrigate by a risk averse producer is appropriately modeled through techniques allowing the effects of risk in decision making models. The major analytic tool for solving decision problems under risk is the expected utility, EU, model. It is assumed a producer maximizes expected utility by allocating the total amount of irrigated acreage available among competing crops.

Consider a producer in a given county engaged in producing n crops over A acres of irrigated land. Let A_i denote acres of the i^{th} irrigated crop with a corresponding yield of Y_i per acre. Yield Y_i is sold at the market price of p_i per unit of yield. The above activity results in the following revenue, R, function for the representative producer

$$R = \sum_{i=1}^{n} p_i Y_i A_i$$

Revenue is a linear function of stochastic prices and yields. By assumption, the vectors of prices $\tilde{P} = p_1, \ldots, p_n$ and yields $\tilde{Y} = Y_1, \ldots, Y_n$ are unobserved at the time of acreage allocation, the vector of acreages $\tilde{A} = A_1, \ldots, A_n$ is to be determined by the producer given the risky revenue R. Let the total variable cost of production, C, be

$$C = \tilde{c}'\tilde{A},$$

where $\mathbf{C} = c_1, \ldots, c_n$ with c_i as the variable cost of production per irrigated acre of the i^{th} crop. It is assumed that this total variable cost, C, for production is known with certainty given input prices and per-acre costs are known at the time of irrigated acreage commitment.

A constraint on the irrigated acreage requires all land be allocated to one of the n crops and that irrigated acreage does not exceed the total available acreage.

(1) $\sum_{i=1}^{n} A_{iy} = A_y, \quad y = 1, 2, \ldots, m.$

Variable A_{iy} denotes the irrigated acres of the i^{th} crop in county y and A_y is the total irrigated acres available in the y^{th} county. A producer also faces a technology constraint represented as

(2) $f(\mathbf{A}) = 0,$

where $f(\mathbf{A}) = 0$ is the production frontier representing the multiproduct multifactor technology of the firm.

If the representative firm maximizes expected utility from total profit, π, under competition, then the decision model is

(3) $\max_{\mathbf{A}} EU(\pi) = \max_{\mathbf{A}} EU(\pi'\mathbf{A}),$

subject to the acreage constraint (1) and technology constraint (2). The profit accruing from the i^{th} crop is

$\pi_i = (p_i Y_i - c_i),$

with $\pi = \pi_1, \ldots, \pi_n$.

Equation (3) indicates that the acreage decision $\mathbf{A}$ is made under both price and production uncertainty. Both yields $\mathbf{Y}$ and output prices $\mathbf{P}$ are random variables with given subjective probability distributions. Consequently, the expectation operator in (3) over the stochastic variables $\mathbf{Y}$ and $\mathbf{P}$ is based on the information available to the firm at planting time.

The optimization model in (3) has direct economic implications for the optimal irrigation acreage allocation, Ã*. If the firm is not risk neutral, the optimal acreage decision will depend not only on expected profits, but also on higher moments of the profit distributions. In case of normally distributed returns, the expected utility criterion is completely specified by the expected value and variance of returns. Otherwise, it is a second-order Taylor series approximation to all risk averse utility functions.

The solution to (3) results in the irrigated acreage allocation equation. The optimal choice of Ã is a function of the following variables and their estimated parameters: expected profits for each crop, **B**, the variance and covariance of these profits, and total irrigated acres A_y available

(4) $A_i^* = A(\mathbf{B}_j, \mathbf{F}_{jj}, \mathbf{F}_{jk}, A_y)$, œ i, j, k = 1, . . . , n, j > k,

where $\mathbf{F}_{jj}$ denotes the variance in profit of the j^{th} crop and $\mathbf{F}_{jk}$ the covariance of profit between the j^{th} and k^{th} crop. The covariance between any two crops, j and k, is included to account for the mechanism of risk-spreading by farmers via the portfolio effect.

The acreage response model (4) may be decomposed into two parts:
the substitution and expansion effects. In making decisions about irrigated acreage allocations, producers may compare the first and second moments of profits of alternative crops. Comparison of expected per-acre profits, and the variance and covariances of recent profits of alternate crops, are assumed to drive the substitution among crops for expected utility maximizing producers.

On the other hand, substitutions between irrigated crops have been accompanied by an overall increase in irrigated acreage over time. Changes in irrigation technology, costs of irrigation, irrigation policy, lender practices relative to irrigation and producer's assessments of future economic conditions in agriculture all may stimulate chances in total irrigated acreage. These causes of chances in total irrigated acreage are partly or wholly independent of year to year variations in relative expected prices, yields, and costs of crops. Specifically, even if relative expected profits of crops remain constant, changes in total irrigated acreage may yield changes in the acreage allocation of crops. These impacts, representing an expansion effect, are captured by the parameters of the total irrigated acreage variable included in each acreage equation.

Application

This acreage response model (4) is applied to a 31-county region in Georgia which approximates the Flint River Basin. These counties, contain a representative crop mix for the state and in 1995 consumed approximately 51% of the state's irrigated water. Based on (4), an agricultural-water demand model for the principal Georgia crops (corn, cotton, peanuts and soybean) by county was developed. Developing such a model required estimating crop irrigated acreage response based on physical, economic and institutional determinants. These estimates of crop acreage by county were then applied to the BC formula for estimating water demand.

With regards to acreage and yield data, there are two major data sources for the analysis, University of Georgia - Cooperative Extension Service (UGA-CES) and the U.S. Department of Agriculture - National Agricultural Statistic Service (USDA-NASS). The state and county acreage irrigation data came from the UGA-CES. A subset of these data is the state irrigated acreage of the i^{th} crop at time period t, which includes all commodity and recreational irrigation groups. Data interpolation for the missing values assumed irrigation acreage increases or decreases linearly between two time intervals. This resulted in a time series of irrigated acreage by crop by county from 1970 through 1998. All harvest data are from NASS. These data are available for 1970 through 1998 and were downloaded from the USDA - NASS web-site http://www.usda.gov/nass/. The data contain the commodity harvested acreage by year for each county.

A major contribution of this analysis is accounting for the influence of economic variables on water demand. Incorporating the profitability of competing crops requires information on prices and costs for a given crop. Price data are from the CD-Rom "Historical Futures Data 1959-Present," 1999 Prophet Financial Systems, Inc. Following Gardner (1976), Chavas, Pope and Kao (1983), Eales *et al.* (1990), Choi and Helmberger (1993), and Holt (1999), futures prices were used to represent expected prices. Weighted average prices in March for harvest-time futures contracts for corn, cotton, and soybeans (December Chicago Board of Trade contract for corn and cotton, November contract for soybeans) were used as a measure of expected prices for these commodities.

A futures market for peanuts does not exist, so price data on seasonal average price for peanuts were collected from 1970 through 1999 editions of *Georgia Agricultural Facts*, published annually by USDA-NASS. Peanut price forecasts were then based on a linear lag price regression.

Yield data were collected for each of the counties from *Georgia Agricultural Facts*. Yield enters the empirical model on a county basis to account for cross-sectional heterogeneity in terms of irrigated acreage. Following Holt (1999), an estimate of expected yields per acre by crop and county was obtained.

Variable cost of production data were collected from the USDA - Economic Research Service (USDA-ERS). The variable cost data are "historical," based on the actual costs incurred by producers in the southeastern U.S. during each year. These cost figures differ from the projection-based budgets put forth by land-grant universities to assist producers in planning. These actual measures of costs incurred are more relevant to the present analysis in considering profitability of competing enterprises. Data were downloaded from the following ERS website: http://www.ers.usda.gov/briefing/farmincome/costsandreturns.htm.

The expression for expected profit per acre for crop i in county y at time t, $E_{t-1}(\mathbf{B}_{iyt})$, is defined as

$$E_{t-1}(\mathbf{B}_{iyt}) = E_{t-1}(p_{it}Y_{iyt}) - c_{it},$$

where p_{it} is the supply inducing price for crop i at time t, Y_{iyt} is yield for crop i in county y at time t and c_{it} is the total variable cost for crop i at time t. Given covariance between yields and prices (Bohrnstedt and Goldberger), expected profits are calculated using

$$E_{t-1}(\mathbf{B}_{iyt}) = E_{t-1}(p_{it})E_{t-1}(Y_{iyt}) + Cov(p_i, Y_{iy}) - c_{it},$$

where $Cov(p_i, Y_{iy})$ is the covariance between price and yield of the i^{th} crop in county y.

As indicated in (4), variances in profits for the crops were included for capturing the risk aversion of producers. The variance associated with profit for the i^{th} crop, $\mathbf{F}_{ii}$, is determined by the three-year period preceding year t (Chavas and Holt). Employing variance directly in the estimation has a limitation of the variable increasing for a random variable with an upward trend even though its relative risk (variance standardized by the mean) may not be increasing. Employing the coefficient of variation eliminates this scaling effect. Similarly, the covariances are calculated using the three-year period preceding year t and are standardized for eliminating the trend effect.

Econometric Model

Given the hypothesis of expected utility maximization and the functional relationship between the optimal irrigated acreage and components of expected utility in (4), the empirical model for optimal irrigated acreage equations is derived as

$$(5) \qquad A^*_{iyt} = \alpha_0 + \sum_{j=1}^{4} \beta_j \pi_{jyt} + \sum_{j=1}^{4} \delta_j \sigma_{jjyt} + \sum_{j=1}^{4}\sum_{\substack{k=1 \\ k>j}}^{4} \gamma_{jk} \sigma_{jkyt} + \eta_i A_{yt} + \sum_{m=1}^{3} \theta_m G_{mt} + \sum_{y=1}^{16} (\lambda_y D_{yt} + \phi_y H_{yt}) + \varepsilon_{iyt},$$

where A^*_{iyt} and π_{iyt} are the number of irrigated acres planted and expected profit per acre, respectively, of the i[th] crop in the y[th] county at time t. The expected per-acre profits are included to capture the substitutability in the crops. Variable σ_{jjyt} is the variance of profit for the j[th] crop in the y[th] county at time t, and is included to account for producer's risk responsiveness. Variable σ_{jkyt} is the covariance of profit between the j[th] and k[th] crop at time t, and is included to capture the portfolio effect relation between the crops. Both σ_{jjyt} and σ_{jkyt} are standardized for eliminating the scale effect. The total irrigated acres in the y[th] county at time t, A_{yt} is included for capturing the expansion effect in irrigated acreage responsiveness. Variables G_m are government program variables for the peanut quota, and set-aside programs for corn and cotton. Dummy variable D_y is a county specific dummy variable accounting for cross sectional heterogeneity in the data, variable H_y is a dummy variable indicating post boll weevil eradication. The last term, ε_{iyt}, is the error term associated with the i[th] crop in the y[th] county at time t. Parameters to be estimated from the data are α_0, β_j, δ_j, γ_{jk}, η_i, θ_m, λ_y, and ϕ_y.

Estimation Results

Assuming the error terms are independent and identically distributed allows estimating (5) by ordinary least squares. The F-test statistic in all acreage equations is significantly different from zero at the 1% level. This suggests a strong rejection of the null hypothesis that all parameters except the intercept are zero. The coefficients of determination, R^2, for the cotton, peanuts, corn and soybean equations are 0.94, 0.93, 0.99 and 0.84, respectively.

Profits of corn are positively related to the irrigated acres of corn. This relationship is statistically significant at the 5% level. As hypothesized, corn profit is positively related to irrigated peanuts at the 1% significance level. Corn is rotated with peanuts for nematode control in peanuts. Corn profits are also negatively related to irrigated soybeans at the 1% level. Soybeans and corn are substitute commodities in crop rotation. The expected profits of cotton, peanuts and soybeans reciprocate the same signs in the corn equation which reinforces the effect of corm profits on irrigated acres of corn, peanuts, and soybeans.

Profits of cotton and soybean are positively related to irrigated acres of cotton at the 1% significance level. This result is consist with the practice of soybeans used in rotation with cotton.

Acreage response of peanuts to its own profit is insignificant at the 5% level. This insignificance may be explained by the constraining role of government poundage quotas on peanuts. Producers of quota peanuts lack the flexibility to adjust their acreage in response to the changes in profitability. The positive and significant at the 1% level of corn profit on peanut irrigated acreage supports the hypothesis of corn used in rotation with peanuts.

The coefficients for expected profits of corn and cotton are both negative and significant at the 1% level. This indicates with enhanced profits of corn and cotton producers will divert irrigated acreage from soybeans to corn and cotton.

Estimated coefficients of variation (or standardized variances) of expected profits are not significantly different from zero even at the 10% level of significance for any crops with the exception of soybeans in the corn equation (at the 5% level) and peanuts in the soybean equation (at the 10% level). Lack of statistical significance on the estimated coefficients of variation suggests that Georgia producers are not risk-averse with respect to profits and government price supports enable them to consider only the expected (mean) profits in making acreage allocation decisions.

Standardized covariances between crops are included to capture the risk-spreading or diversifying behavior of producers. Out of 24 (six in each of the four models) associated coefficients half are significant at the 10% level. These relationships suggest a portfolio effect among the crops.

The coefficient associated with total irrigated acreage in a county, TIA_{yt}, has the expected positive sign and is significantly different from zero at the 1% level in the corn and peanut equations, at the 5% level in the soybean equation, and at the 10% level in the cotton equation. As far as responsiveness to TIA is concerned, peanuts are the most responsive among the four crops, with a coefficient estimate of 0.260. Similarly, an acre increase in TIA induces a 0.177 acre increase in corn, a 0.079 acre increase in cotton, and a 0.046 acre increase in soybeans.

There were three government program variables considered in the study: corn set-aside, cotton set-aside, and the peanut quota variable weighted by average peanut acreage per county. Out of these three variables, only the coefficient associated with corn set-aside, in the corn irrigated acreage equation, does not have the expected (negative) sign. However, this estimate is statistically highly insignificant. Thus, the corn set-aside program does not seem to affect the response in irrigated acreage of corn. This program does seem to affect the acreage allocation in cotton, as given by the 1%significance level of the coefficient associated with corn set-aside in the cotton equation.

The coefficient associated with cotton set-aside is significant at the 1% level and has the expected (negative) sign in the cotton equation. Also, the relevant coefficient estimate is high, -175.22, indicating 175.22 acres of cotton being taken out of production with a one unit increase in the set-aside requirement. Corn irrigated acreage is positively affected by the cotton set-aside program at the 1% significance level. The relevant coefficient estimate of 77.88 suggests that a one unit increase in cotton specified by the cotton set-aside program raises corn irrigated acreage by 77.88 acres.

Both the set-aside programs have a positive significant effect (at the 1% level) on peanut irrigated acreage. However, they have no effect on soybean irrigation acreage. This indicates a one unit increase in corn, by the corn set-aside program provision, causes 159.47 acres of cotton to be taken out of production and replaced with 82.96 acres of peanuts, and the rest 76.51 acres may be of other crops not included in this analysis. Similarly, the one unit increase in the cotton set-aside program provision causes 175.22 acres of irrigated cotton taken out of production and replaced with 77.88 acres of corn, 57.48 acres of peanuts, and the rest 39.86 acres may be of other crops not included in this analysis.

In terms of the dummy variables, there are two such sets of dummy variables. The first set is included in the econometric model to account for any heterogeneous county effects across the counties, including differences in soil and environmental conditions. Each is an indicator variable contrasted against the county group categorized as Other. Most of these county dummy coefficients (49 out of 64) are significant at the 10% level. In particular, soybeans have 14 out of16 of county dummies significant at the 1% level. Corn and cotton have 13 significant county dummy coefficients. In contrast, peanuts have only 9 out of 16 county dummies statistically significant. Producers of peanuts show the least amount of heterogeneity in production relative to county group Other as compared to the other three crops.

The second set of intercept-shifting dummy variables is included to upward jump in cotton yield, possibly as a result of boll weevil eradication, across counties after 1992. Out of a total of 64 possible estimates, 38 of the dummies demonstrate statistical significance at the 10% level – nine each for corn, cotton and soybeans, and 11 for peanuts.

Slippage

Changes in water demand are driven by changes in the distribution of crops producers choose to irrigate from year to year. These changes in crop distribution are in turn affected by their expected profitability and total available irrigated acreage. Conventional physical models do not consider the substitution and expansion effects in determining agricultural water demand. In contrast, the econometric model considers these effects. The difference in the estimates of water demand is slippage. This slippage may result in a higher or lower expected water use depending on the effect of relative profitability.

Slippage is measured by comparing the reduction in estimates of water demand, resulting from restrictions on total irrigated acreage available in a county, based on the physical model versus the econometric estimates of (5). The physical model computations of changes in water demand are calculated on a county basis. First, the crop distribution is calculated by dividing irrigated acreage of each of the four crops in a county by the total irrigated acreage in the county. Second, the calculated weights are multiplied by the reduction in total irrigated acreage in a county in 2001. Third, the weighted reduction in acreage is multiplied by the region-specific BC coefficient. Finally, the changes in water demand in the four crops are summed up over the counties to give the total 2001 decrease in water demand. The physical calculations of crop distribution are summarized in table 1.

The expected profits and yields are calculated by applying the coefficients from the estimated econometric model (5) to data for years 2000 and 2001. Data years 2000 and 2001 were obtained from the same data sources used in data collection for the econometric model. While data on market and government prices were available from the sources, cost and yield used in forecasting maintain the same assumptions as in the estimation of (5). Yield data for 2000 and 2001 are assumed to remain constant at the average level of 1994 through 1998. Variable cost data are extrapolated using the 1999 level of variable cost. The cost series is adjusted for inflation by the average cost index for the years 1994 through 1998.

Econometric forecasts for corn, cotton, peanut and soybean irrigated acreage in 2000 and 2001 combined are 528,149 acres. Under the econometric technique, a change in price results in altering the distribution of the crop mix. Changes in irrigated acres and the crop distribution are listed in table 1. The change in irrigated acreage and crop distributions estimates are used in conjunction with the BC coefficients to estimate slippage. Assuming a normal weather year, the slippage estimate is calculated in table 2.

In disregarding price effects, the physical model implicitly assumes the irrigated crop distribution remains constant between 2000 and 2001. On the other hand, the econometric model allows an adjustment in acreage distribution to reflect the role of expected profits, risk aversion and total irrigated acreage in a producer's irrigated acreage allocation decision. The differences in techniques result in a slippage amount of approximately -17.7%. This amount of slippage states the physical technique under-predicts water savings by approximately 50.9 million gallons per day. Thus, failure to consider the economic substitution and expansion effects has lead to erroneous policy analysis.

Conclusion

Incorporating price effects in the acreage allocation decision leads to slippage in the measurement of water demand. This study has attempted to identify the presence of slippage and the pitfalls associated with disregarding it in measuring changes in water demand. Considering slippage is a first attempt in determining the effectiveness of water conserving initiatives such as the Flint River Drought Protection Act. Currently, policy makers are assuming a certain level of decrease in irrigation water demand as a result of reducing the total irrigated acreage. The decrease in water demand is then in turn assumed to benefit both the interstate and intrastate allocation of water from the Flint River. The policy makers indicate increased water flows will result for Alabama and Florida as well as more water for the competing users within the state. In considering the dynamic price effects in acreage allocation, policy makers may be better equipped to assess the net change in water demand. Greater precision in information is beneficial given a larger than expected reduction in water demand implies decreased government expenditures on payments to farmers to not irrigate in auctions such as the one used in the FRDPA.

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Table 1. Physical and Econometric Estimates of Crop Distribution and Change in Total Irrigated Acres 2000 - 2001

Crop	Irrigated Acreage (1,000's)			Crop Distribution[b]	
	2000	2001[a]			
		Physical	Econometric	Physical	Econometric
Corn	119	112 (-7)	125 (6)	0.212	0.237
Cotton	237	223 (-14)	198 (-39)	0.422	0.375
Peanuts	177	167 (-10)	161 (-16)	0.315	0.305
Soybeans	29	27 (-2)	44 (15)	0.052	0.083
Total	562	529 (-33)	528 (-34)		

[a] Numbers in parentheses are the difference in 2001 and 2000 irrigated acreage.

[b] Crop Distribution = Irrigated Acres$_i$ / Total Irrigated Acres, i = corn, cotton, peanut and soybeans.

Table 2. Slippage in Measuring Change in Water Demand 2000 - 2001[a]

Crop	BC Coefficient[b].	Change in Water Demand (1,000 acre-feet)[c] Physical	Econometric	Slippage[d]
Corn	11.20	-78.4	67.2	
Cotton	11.77	-164.8	-459.0	
Peanuts	6.37	-63.7	-101.9	
Soybean	7.59	-15.9	113.9	
Total		-322.8	-379.8	-0.177

[a] Slippage measure assumes a normal weather year.

[b] Blaney-Criddle (BC) formula.

[c] Water demand is calculated by multiplying a crop's change in total irrigated acreage by the BC coefficient.

Note, one acre foot equals 325,800 gallons.

[d] Slippage is equal to one minus the ratio of the econometric to the physical decrease in total water demand