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Forecasting Irrigation Water Demand: A Case Study on the Flint River Basin in Georgia

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Southeast drought conditions have accentuated the demand for irrigation in the face of restricted water supply. For allocating this supply, Georgia held an auction for withdrawing irrigated acreage. This auction withdrew 33,000 acres from irrigation, resulting in a physical estimate of a 399 acre-feet daily increase in water flow. The actual reduction is driven by crop distributional changes on the basis of economic substitution and expansion effects. In contrast to the physical estimates, an econometric model that considers these effects is developed. The differences between the physical and econometric models result in an increase in the estimate of water savings of around 19% to 24%.

Key Words: acreage response, crop distribution, irrigated acreage, irrigation, slippage, water demand, water saving

JEL Classifications: Q12, Q25

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 U.S. Department of Agriculture–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 lawsuits among these states. According to this study, agriculture within Georgia is the major consumptive water user. More than 21,000 water withdrawal permits, each representing an irrigation pump with over a 100,000 gallon/day capacity, are held by Georgia agricultural producers. The permits, grandfathered under law, stay with the land, with no use-it-or-lose provisions. The permits allow producers to withdraw as much water as they can for use in producing any commodity. With the value they add to the land and the correct moratorium on permits, there is little incentive for producers to use the free water more efficiently and no incentive to return permits to Georgia's Environmental Protection Division (EPD) (Dodd).

Attempting to move toward an efficient water management program within the tri-state area, the Georgia legislature in 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

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using perennial surface water sources. The objective of this auction was to increase the Flint River water flow, which was adversely affected by the recent drought in the southeastern United States. On March 17, 2001, bids by producers to suspend irrigation were submitted. If a bid was accepted by the EPD, a producer would then agree not to use irrigation on the land for the 2001 growing season. After five rounds of auction, EPD declared the auction closed and accepted 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. The EPD estimated removing 33,000 acres from direct surface water irrigation would result in approximately a 399 acre-foot daily increase in the Flint River water flow and its tributaries (Georgia Environmental Protection Division). Such an increase would aid in mitigating the drought conditions.

This estimate of water savings from reduced crop irrigation acreage is obtained by the use of engineering consumption water use models. Consumptive water requirement is a major component in the denominator of equations for establishing irrigation water usage. Irrigation engineers have developed models for measuring and predicting per-acre consumptive water requirements for alternative crops. Extensive literature reviews of these physical models are provided by Burt et al. and Mutziger et al. One common consumption water use model is the Blaney–Criddle (BC) formula (USDA–Soil Conservation Service). 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.

With the predicted per-acre water demand for each crop, the total regional demand for irrigation water can be determined by multiplying this crop water demand per acre by the respective acreage. By inverting this method, the EPD arrived at its 399 acre-feet daily increase when removing 33,000 acres from irrigation.

This conventional physical approach to estimating water demand makes a number of major assumptions. It assumes an instantaneous return flow, which might not generally be the case for surface water–based irrigation across the United States. Also, it does not consider "deficit irrigation," in which there are economic efficiency gains to apply less-than-full consumptive water requirements.

A third assumption made by EPD in their water savings forecast is the focus of this study. EPD's approach assumed the distribution of irrigated crops remained unchanged after an irrigated acreage reduction. This distribution of irrigated acreage across crops is a key determinant of water usage with some crops (e.g., corn, cotton) having higher water requirements than others (e.g., peanut, soybean). With crop acreage distributions generally changing from year to year in response to changes in expectations for returns, the assumption of a constant crop distribution could lead to significant errors in water use (savings) estimates. This is especially true in times of significant changes in relative returns of alternative crops.

Relaxing the assumption of a fixed cropping distribution, the actual reduction in water use from reduced irrigated acreage is dependent on changes in the distribution of crops producers irrigate. As outlined in the Theoretical Model section, a change in crop distribution is generally driven by the expected relative profitability of competing crops. Changes in agricultural economic and institutional conditions can result in substitution and expansion effects, which will alter the crop distribution. Substitution effects measure the possibility of a producer substituting one crop for another because of a change in relative expected risks and returns. Expansion effects measure the possible change in crop distribution resulting from a change in total irrigated acreage. In the EPD acreage reduction case, the auction resulted in reduced total irrigated acreage leading to a negative expansion effect. The conventional physical approach does not consider these substitution and expansion effects in determining agricultural water demand.

In an attempt to improve EPD's water savings estimates, we incorporate an econometric acreage allocation model into the water use policy simulation. For reporting purposes, we call the difference between EPD's constant distribution estimate of the change in water demand and our flexible distribution estimate "slippage." Analysis of FRDPA indicates slippage of 19% or 24%, depending on the model assumptions.

The underlying acreage response model for predicting crop acreage is developed in the following section. This theoretical foundation is followed by a section describing the data and methods for estimating the response model. The econometric model and associated results are then presented. From these results, predicted crop distributions are estimated and used in conjunction with the BC formula to estimate water savings from the auction. The discrepancies between the physical model, which assumes a static crop distribution, and the econometric model, which allows for distributional shift on the basis of economic and institutional determinants, are then compared in terms of measuring slippage.

Theoretical Model

Reviewing the literature on acreage response modeling, Nerlove wrote a seminal article on partial adjustment and adaptive expectations models. Since Nerlove, estimation of acreage response has resulted in a whole body of literature: studies have incorporated the role of government programs (Chembezi and Womack; Duffy, Richardson, and Wohlgenant; Houck and Ryan; Massow and Weersink; McIntosh and Shideed; Morzuch, Weaver, and Helmberger; Shideed, White, and Brannen), considered alternative expected market price (Chavas, Pope, and Kao; Duffy, Richardson, and Wohlgenant; Gardner; Morzuch, Weaver, and Helmberger; Shumway), incorporated the role of risk in acreage allocation with the use of expected utility theory (Chavas and Holt; Duffy, Shalshali, and Kinnucan; Just; Krause, Lee, and Koo; Lin; Nieuwoud, Womack, and Johnson; Pope and Just; Traill), and specified a system of crop acreage (Bewley et al.; Binkley and McKinzie; Colman; Coyle; Kraker and Paddock).

Recent studies have examined acreage response with risk in a systems framework (Barten and Vanloot; Bettendorf and Blomme; Holt). The Bettendorf and Blomme and Barten and Vanloot models are developed as first-order differential acreage allocation models that use the basic mean variance utility framework. They are consistent with certainty equivalent profit maximization and constant absolute risk aversion. Holt extends the analysis to deal with cross-sectional and panel data. On the basis of Holt's extension, the following acreage response model is developed for estimating crop distributions applied to predicting water savings from the EPD auction.

Consider a producer 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 per-unit market price of p_i. 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 $\overline{P}\ 1 = (p_1, \ldots, p_n)$ and yields $\overline{Y} = (Y_1, \ldots, Y_n)$ are unobserved at the time of acreage allocation, and the 1vector of acreages $\overline{A} = (A_1, \ldots, A_n)$ is to be determined by the producer given the risky revenue R. Let the total variable cost of production, C, be

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

where $\overline{c} = c_1, \ldots, c_n$, 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, A_i, requires that all land be allocated to one of the n crops and that irrigated acreage does not exceed the total available acreage,

$$(1) \quad \sum_{i=1}^{n} A_i = A.$$

A producer also faces technology and institutional constraints represented as

$$(2) \quad \overline{T}(\overline{A}) = 0$$

and

$$(3) \quad \overline{G}(\overline{A}) = 0,$$

where $\overline{T}(\overline{A}) = 0$ is the production frontier representing the multiproduct, multifactor technology of the firm, and $\overline{G}(\overline{A}) = 0$ is an agricultural government constraint representing quotas and set-aside provisions.

Following Holt (p. 384), we assume that a representative producer makes decisions about which crops to grow in a manner similar to that of an investor determining the composition of an investment portfolio. If the representative firm maximizes expected utility from total profit, $\overline{\pi}$, under competition, then the decision model is

$$(4) \quad \max_{\overline{A}} EU(\pi) = \max_{\overline{A}} EU(\overline{\pi}'\overline{A}),$$

subject to the acreage (Equation [1]), the technology (Equation [2]), and the institution constraints (Equation [3]). The choice variable is crop acreage, $\overline{A}$, with other variables: profit, $\overline{\pi}$, total acreage, A, technology, $\overline{T}$, and institutional constraints, $\overline{G}$. The profit accruing from the i^{th} crop is

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

with $\overline{\pi} = (\pi_1, \ldots, \pi_n)$.

Equation (4) indicates that the acreage decision, $\overline{A}$ is made under both price and production uncertainties. Both yields ($\overline{Y}$) and output prices ($\overline{P}$) are random variables with given subjective probability distributions. Consequently, the expectation operator in Equation (4) over the stochastic variables $\overline{Y}$ and $\overline{P}$ is based on the information available to the firm at planting. The optimization model in Equation (4) has direct economic implications for the optimal irrigation acreage allocation, $\overline{A}^*$. 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 the 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 first-order condition to Equation (4), assuming a second-order Taylor series, results in the irrigated acreage allocation model. The optimal choice of $\overline{A}$ is a function of expected profits for each crop ($\overline{\pi}$), the variance and covariance of these profits, total irrigated acres (A), technology ($\overline{T}$), and governmental programs ($\overline{G}$):

$$(5) \quad \begin{aligned} &A_i^* = A(\overline{\pi}, \sigma_{jj}, \sigma_{jk}, A, \overline{T}, \overline{G}), \\ &\forall i, j, k = 1, \ldots, n, \qquad j > k, \end{aligned}$$

where σ_{jj} denotes the variance in profit of the j^{th} crop and σ_{jk} the covariance of profit between the j^{th} and k^{th} crops. 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 Equation (5) can be decomposed into two parts: the substitution and expansion effects. In making decisions about irrigated acreage allocations, producers can compare the first and second moments of profits for alternative crops. Comparison of expected per-acre profits and the variances and covariances of recent profits of alternative crops are assumed to drive the substitution among crops for expected utility maximizing producers.

This substitution among irrigated crops has also been accompanied by an overall expansion in irrigated acreage over time. Changes in irrigation technology, costs of irrigation, irrigation policy, lender practices relative to irrigation, and producers' assessments of future economic conditions in agriculture could stimulate changes in total irrigated acreage. These causes of changes in total irrigated acreage are partly or wholly independent of year-to-year variations in relative expected prices, yields, and costs of crops. Even if relative expected profits of crops remain constant, changes in total irrigated acreage could yield changes in the acreage allocation of crops. These effects, representing an expansion effect, are captured by the parameters of the total irrigated acreage variable included in each acreage equation.

Mating the economic model of Equation (5) with the BC formula integrates economic conditions into estimates of agricultural water demand. With this integration, producers' response to economic conditions and institutional policies can be addressed in determining agriculture's thirst for water. Specifically, instead of assuming that crop distribution remains static and applying the past distribution to the BC formula, Equation (5) allows this distribution to vary on the basis of expected economic conditions. In this manner, economic conditions are integrated into estimates of water demand.

Data and Methods

This acreage response model of Equation (5) is applied, with the use of county-level data, 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. Fifteen Flint River Basin counties that have minimal irrigated acreage are aggregated, resulting in 17 cross-sectional observations (16 unique counties and one aggregate). On the basis of Equation (5), an agricultural water demand model for the principal Georgia crops (corn, cotton, peanut, and soybean) by county is developed. Developing such a model requires estimating crop irrigated acreage response on the basis of physical, economic, and institutional determinants. These estimates of crop acreage by county are then applied to the BC formula for estimating water demand. Data used for this application are subject to error, so attention to data quality is warranted when applying this model for policy analysis. For example, cost and return data collected by the USDA–Economic Research Service (USDA–ERS) before 1995 might require reconciling with data since 1995, and the assumption of the Law of One Price holding across counties could be too restrictive.

Two major data sources used in this analysis for acreage and yield data are the University of Georgia–Cooperative Extension Service (UGA–CES) and the USDA–National Agricultural Statistics 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. This data subset consists of years 1970, 1975, 1977, 1980, 1982, 1986, 1989, 1992, 1995, and 1998. County harvested acres by crop were available for 1970 through 1998. Data interpolation for the missing values assumes irrigation acreage increased or decreased linearly between two time intervals. This results in a time series of irrigated acreage by crop by county from 1979 through 1998. Unfortunately, subsequent yearly data for irrigated acreage by crop by county are not consistently available. All harvest data, including commodity harvested acreage by year by county for the period 1979 to 1998, were downloaded from the USDA–NASS website (http://www.nass.usda.gov/).

Price data are from the CD-ROM "Historical Futures Data 1959–Present" (Prophet Financial Systems, Inc.). Following Chavas, Pope, and Kao; Choi and Helmberger; Eales et al.; Gardner; and Holt, futures prices are used to represent expected prices. Weighted average prices in March for harvest-time futures contracts for corn, cotton, and soybean (December contract for corn and cotton, November contract for soybean) are used as a measure of expected prices for these commodities. A futures market for peanut does not exist, so price data on seasonal average prices for peanut were collected from the 1970 through 1999 editions of *Georgia Agricultural Facts*, published annually by USDA–NASS. Peanut price forecasts are 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, an estimate of expected yields per acre by crop and county is calculated by dropping the high and low yields for crop i in county m for the preceding 6 years, averaging the remaining four annual yields, and adding an adjustment parameter, δ_{im}, to assure that deviations between observed and expected yields sum to zero over the sample period,

$$Y^c_{imt} = \delta_{im} + \frac{1}{4}\left[\sum_{k=1}^{6} Y_{imt-k} - \max(Y_{imt-1}, \ldots, Y_{imt-6}) - \min(Y_{imt-1}, \ldots, Y_{imt-6})\right].$$

Variable cost of production data were collected from USDA–ERS. The variable cost data are "historical" and based on the actual costs incurred by producers in the southeastern United States 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 on costs were downloaded from the ERS website (http://www.ers.usda.gov/briefing/farmincome.htm).

The expression for expected profit per acre for crop i in county m at time t, $E_{t-1}(\pi_{imt})$, is defined as

$$E_{t-1}(\pi_{imt}) = E_{t-1}(p_{it} Y_{imt}) - c_{it},$$

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

$$E_{t-1}(\pi_{imt}) = E_{t-1}(p_{it})E_{t-1}(Y_{imt}) + \text{Cov}(p_{it}, Y_{imt}) - c_{it},$$

where $\text{Cov}(p_{it}, Y_{imt})$ is the covariance between price and yield of the i^{th} crop in county m.

As indicated in Equation (5), variances in profits for the crops are included for capturing the risk aversion of producers. Variances and covariances of expected profits were based on forecast errors with use of the expectation generating processes for prices and yields described above. Following Chavas and Holt, we calculate variances and covariances on the basis of the 3-year period preceding year t. Employing variance directly in the estimation has the limitation that it increases for a variable with an upward trend even though the relative risk (variance standardized by the mean) might not be increasing. Employing the coefficient of variation eliminates this scaling effect. Similarly, the covariances are calculated with the 3-year period preceding year t and standardized for eliminating the trend effect.

Data summary statistics for the explanatory variables are presented in Table 1. The irrigated acreage spans a large range. One possible explanation of the large range is the time period of the data. Relative to the early 1970s, adoption of irrigation technology was rapid in the late 1970s through 1980s. Adoption was primarily driven by credit agencies requiring producers to irrigate a proportion of their land to minimize the downside risk associated with poor yields.

Econometric Model

Given the hypothesis of expected utility maximization and the functional relationship between the optimal irrigated acreage and components of expected utility in Equation (5), the empirical model for optimal irrigated acreage equations is

Table 1. Summary Statistics[a]

Variable[b]	Mean	SD	Minimum	Maximum
Irrigated acres				
Corn	7,257.93	4,305.92	500	20,197.52
Cotton	6,551.89	7,495.47	0	36,201.20
Peanut	10,042.25	5,143.44	2,178.56	25,292.97
Soybean	2,551.99	2,318.96	279.91	12,939.66
Profit				
Corn				
Mean	119.73	66.59	−12.87	312.46
Variance	86.81	175.12	1.44	2,416.78
Cotton				
Mean	171.91	127.67	−87.82	515.32
Variance	11,720.96	184,055.01	0.5	3,129,282.50
Peanut				
Mean	510.49	136.93	147.73	817.50
Variance	43.12	53.02	1.33	431.95
Soybean				
Mean	71.61	28.79	4.69	151.25
Variance	32.8	56.69	0.36	718.07
Covariance				
Corn–Cotton	94.3	353.67	−4,051.13	2,239.38
Corn–Peanut	11.46	24.27	−32.88	156.05
Corn–Soybean	15.24	39.53	−133.78	354.13
Cotton–Peanut	30.84	61.15	−63.43	333.97
Cotton–Soybean	−2.43	298.58	−4,341.23	929.05
Peanut–Soybean	9.12	21.55	−19.81	162.63
Total irrigated acres	36,501.91	18,562.87	8,288.00	92,508.00
Government programs				
Peanut quota	3,994.04	2,021.89	1,532.04	10,232.53
Corn set-aside	8.68	6.26	0	20
Cotton set-aside	12.56	9.28	0	25

[a] Observations: 1982–1998, 17 years with 17 counties, 289 observations for all the variables.
[b] Variance and covariance measured as coefficient of variation.

(6)
$$
\begin{aligned}
A^*_{imt} &= \alpha_0 + \sum_{j=1}^{4} \beta_j \pi_{jmt} + \sum_{j=1}^{4} \gamma_j \sigma_{jjmt} \\
&+ \sum_{j=1}^{4} \sum_{\substack{k=1 \\ k>j}}^{4} \delta_{jk} \sigma_{jkmt} + \eta_i A_{mt} \\
&+ \sum_{r=1}^{3} \Gamma_r G_{rt} + \sum_{m=1}^{16} \theta_m D_{mt} \\
&+ \sum_{m=1}^{16} \Phi_m E_{mt} + \varepsilon_{imt},
\end{aligned}
$$

where A^*_{imt} and π_{imt} are the number of irrigated acres planted and expected profit per acre, respectively, of the i^{th} crop in the m^{th} county at time t. The expected per-acre profits are included to capture the substitutability in the crops. Variable σ_{jjmt} is the variance of profit for the j^{th} crop in the m^{th} county at time t, and is included to account for producer's risk responsiveness. Variable σ_{jkmt} is the covariance of profit between the j^{th} and k^{th} crops at time t, and is included to capture the portfolio effect relation between the crops. Both σ_{jjmt} and σ_{jkmt} are standardized for eliminating the scale effect. The total irrigated acres in the m^{th} county at time t, A_{mt}, is included for capturing the expansion effect in irrigated acreage responsiveness. The G_r are government program variables for the peanut quota and set-aside programs for corn and

Table 2. Expected Directional Effect of a Crop's Irrigated Acreage

	Expected Direction of Irrigated Acreage for the i^{th} Crop[a]	
Variable	Economic Theory	Agronomic
Profit		
Mean, i^{th} crop (π_{imt})	+	
Mean, j^{th} crop (π_{jmt})	−	− if substitute crop + if rotation crop
Variance, i^{th} crop (σ_{iimt})	−	
Variance, i^{th} crop (σ_{iimt})	+	+ if substitute crop − if rotation crop
Covariance, i^{th} and j^{th} crop (σ_{ijmt})	−	
Covariance, j^{th} and k^{th} crop (σ_{jkmt})	+	
Total irrigated acres (A_{mt})	+	
Peanut quota, i^{th} crop is peanut	+	
i^{th} crop is other than peanut	−	
Corn set-aside, i^{th} crop is corn	−	
i^{th} crop is other than corn	+	
Cotton set-aside, i^{th} crop is cotton	−	
i^{th} crop is other than cotton	+	

[a] i^{th} crop refers to the crop associated with the dependent variable, and j^{th} and k^{th} crops refer to the remaining three crops.

cotton, and dummy variables D_{mt} and E_{mt} are county-specific dummy variables accounting for cross-sectional heterogeneity in the data and boll weevil eradication, respectively:

$$D_{mt} = \begin{cases} 1 \text{ if county } m, \\ 0 \text{ otherwise,} \end{cases}$$

$$E_{mt} = \begin{cases} 1 \text{ if post boll weevil eradication, } > 1992, \\ 0 \text{ otherwise.} \end{cases}$$

The county dummy variables attempt to capture technology shifts in acreage response not accounted for by the other explanatory variables. Such shifts include variations in land topology, soil types, and agricultural infrastructure for particular crops. The boll weevil dummy variable is designed to capture the structural shift in cotton production technology response after eradication. The last term, ε_{imt}, is the error term associated with the i^{th} crop in the m^{th} county at time t. Parameters to be estimated from the data are α_0, β_j, γ_j, δ_{jk}, η_i, Γ_r, θ_m, and Φ_m.

Hypothesized relationships between irrigated acreage of a crop and each of the variables in Equation (5) are based on economic theory and agronomic relationships (rotational considerations) among the crops. The expected signs on estimated regression coefficients are summarized in Table 2.

The expected utility function of a risk-averse producer in a competitive setting is concave. In the model context, concavity of the expected utility function implies that it is a monotonically increasing function of own profits. Hence, a positive sign is expected on the coefficient associated with profit for the i^{th} crop. Risk aversion implies expected utility will be a decreasing function of variance in the profit of the i^{th} crop. Therefore, an inverse relationship is hypothesized between irrigated acres committed to the i^{th} crop and variance in own profit.

In an allocation model, crops can have a substitution, complementary, or no relationship at all. If two crops are substitutes for each other, then they are expected to be negatively related to each other in the producer's acreage allocation decision. Increasing profitability in a competing crop, say the j^{th} crop, is expected to lower acreage commitments for crop i. On the contrary, rising profits in the i^{th} crop could result in rising levels of acreage committed to the j^{th} crop that serves as a rotation crop. Specifically, in Georgia, corn and soybean are substitutes in rotation with cotton and peanut. With regard to variation in the profit of an alternative crop, say *j*, it is expected that rising variability in crop *j*'s profit will positively (negatively) influence irrigated acreage of a substitute (complement) i^{th} crop.

A negative correlation between two crops in a producer's portfolio reduces the farmer's risk. Thus, for the i^{th} crop, it is expected that a negative sign will be associated with the covariance variable. However, comparing the covariance between other non-*i* crops, a reduced risk scenario suggests taking irrigated acres out of production for the i^{th} crop and committing acreage to some combination of the other two crops as the correlation of these other crops declines. A positive relationship is the expected sign in this case.

Addition to total irrigated acreage is expected to yield increases in individual crop acreage, and it is hypothesized that an increase in quota peanut will enhance peanut acreage at the expense of other crops. In contrast, it is expected an increase in the set-aside provision for corn or cotton will be offset with acreage increases in the alternative crops.

Estimation Results

Assuming the error terms are independently and identically distributed allows estimating Equation (6) by ordinary least squares. All four equations (corn, cotton, peanut, and soybean), each with 289 observations, 17 years, and 17 counties, are specified as functions of an intercept term, profits, variance and covariance of profits for each crop, the total irrigated acreage by county, government program variables, and county-specific dummy variables. Parameter estimates for each crop are presented in Table 3.

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 corn, cotton, peanut, and soybean equations are 0.94, 0.93, 0.99, and 0.84, respectively.

Profits of corn and cotton are positively related to their corresponding irrigated acres at the 1% significance level. As hypothesized, corn and cotton profits have inverse relationships in the soybean equation, and cotton also maintains this negative relation in the corn equation. Corn and soybean are substitutes in crop rotation, which further accounts for their negative relationships in the equations. Consistent with the practice of soybean used in rotation with cotton, soybean profit is positively related to cotton irrigated acreage at the 10% significance level.

The acreage response of peanut to its own profit is not significant at the 10% level. This lack of significance may be explained by the constraining role of government poundage quotas on peanut. Producers of quota peanut do not have the flexibility to adjust their acreage in response to the changes in profitability. These results are based on quota prices; therefore, total acreage adjustment in peanut is not readily expected. The producers with quota provisions would commit acreage to insure meeting the quota poundage and would entertain other crops only for their rotation considerations. This is evident by the positive coefficient, significant at the 1% level, associated with the cross-profitability of corn. Corn is rotated with peanut for nematode control, which accounts for the positive significance level of corn profit in the peanut equation.

In the soybean acreage response, the coefficient for soybean profit is also not significant at the 10% level. A possible explanation for this lack of significance is the minor role of soybean in Georgia agriculture. It is grown primarily for its rotational considerations. Soybean is rotated with cotton and peanut given its nematode-resistant properties. The decision to commit irrigated acres of land into soybean might be driven less by profit consideration and more by rotational consideration.

Estimated coefficients of variation for profits are not significantly different from zero even at a 10% level of significance for any crop, with the exception of soybean in the corn equation and peanut in the soybean

Table 3. Estimated Coefficients,[a] Irrigated Acreage Models[b]

Variable[c]	Corn	Cotton	Peanut	Soybean
Intercept Profit	5,134.30 (1,239.17)	6,191.76*** (2,330.33)	−3,861.02 (624.15)	8,868.61* (1,094.65)
Corn				
Mean	9.88*** (3.90)	−4.50 (7.34)	5.42*** (1.97)	−12.88*** (3.45)
Variance	−0.28 (0.50)	1.12 (0.93)	−0.39 (0.25)	−0.33 (0.44)
Cotton				
Mean	−9.04*** (1.56)	18.25*** (2.94)	−0.26 (0.79)	−7.92*** (1.38)
Variance	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	−0.00 (0.00)
Peanut				
Mean	1.29 (2.08)	0.89 (3.91)	−0.72 (1.05)	−2.51 (1.84)
Variance	−0.98 (3.87)	6.91 (7.28)	−0.76 (1.95)	−6.47* (3.41)
Soybean				
Mean	−11.13** (5.45)	19.07* (10.25)	1.73 (2.75)	6.83 (4.82)
Variance	−4.69** (2.34)	6.48 (4.41)	−1.89 (1.18)	−2.09 (2.07)
Covariance				
Corn–Cotton	−0.09 (0.22)	0.13 (0.41)	−0.06 (0.11)	0.04 (0.19)
Corn–Peanut	−9.02* (5.17)	26.01*** (9.72)	3.90 (2.60)	−10.99** (4.57)
Corn–Soybean	4.90* (5.26)	−12.16** (2.80)	−1.38 (1.41)	8.29*** (2.47)
Cotton–Peanut	3.11 (2.17)	3.38 (4.08)	2.20*** (1.94)	−3.95** (1.92)
Cotton–Soybean	−0.14 (0.27)	0.09 (0.51)	0.11 (0.14)	−0.23 (0.24)
Peanut–Soybean	19.40** (9.56)	−61.78*** (17.98)	8.84* (4.81)	16.07* (8.44)
Total irrigated acres	0.18*** (0.02)	0.08* (0.04)	0.26*** (0.01)	0.04** (0.02)
Government programs				
Peanut quota	−0.98*** (0.28)	−0.47 (0.53)	0.71*** (0.14)	−1.15*** (0.25)
Corn set-aside	16.22 (25.52)	−159.47*** (47.99)	82.96*** (12.85)	−9.21 (22.54)
Cotton set-aside	77.88*** (17.81)	−175.22*** (33.50)	57.48*** (8.97)	5.41 (15.74)
Model fit				
F-value	75.89***	64.35***	448.85***	25.22***
Mean square error	1,150.70	2,163.96	579.59	1,016.50
R^2	0.94	0.93	0.99	0.84

[a] Standard errors are in parentheses.
[b] Estimates of the county dummy and boll weevil coefficients are available from the authors.
[c] Variance and covariance measured as coefficient of variation.
* Significantly different from zero at the 10% level.
** Significantly different from zero at the 5% level.
*** Significantly different from zero at the 1% level.

equation. Lack of statistical significance on the estimated coefficients of variation suggests that Georgia producers are not risk-averse with respect to profit. Government price supports enable producers to consider only the expected mean of profits in making acreage allocation decisions.

Parameters associated with covariance between crops, hypothesized to capture the risk-spreading behavior of the producers, are significantly different from zero, at least at the 10% level, in half the instances. However, only one fourth of these significant coefficients have the hypothesized correct sign. Agronomic constraints affecting crop correlations, such as rotation, might interfere with the portfolio desires of producers.

The parameter estimate associated with total irrigated acreage in a county, A_{mt}, has the expected positive sign and is significantly different from zero at the 1% level in the corn and peanut equations, and at the 5% and 10% levels, respectively, for soybean and cotton. In terms of mean elasticities, in response to

Table 4. Change in Irrigated Acreage and Crop Distribution, 2000–2001

	Irrigated Acreage				Crop Distribution[c]		
		2001[b]					
			Econometric[d]			Econometric	
Crop	2000[a]	Physical	Simultaneous	Sequential	Physical	Simultaneous	Sequential
Corn	119,044	113,483	124,927	124,778	0.152	0.166	0.166
Cotton	237,140	227,389	198,042	192,671	0.302	0.263	0.256
Peanut	177,184	169,641	161,073	162,600	0.226	0.214	0.216
Soybean	29,291	27,766	44,107	43,118	0.037	0.059	0.057
Other	222,157	213,531	223,661	228,642	0.283	0.297	0.304
Total	784,816	751,810	751,810	751,810			
		(−33,006)	(−33,006)	(−33,006)			

[a] Irrigated acreage for year 2000 summed over all the counties (Source: UGA–CES).

[b] Physical and econometric irrigated acreage for year 2001 are calculated on a county basis and then summed over the counties. For the physical (econometric) model, the 2000 (predicted 2001) irrigated crop distribution within a county is multiplied by the county reduction in total irrigated acreage from the EPD auction. Numbers in parentheses are the difference in 2001 from 2000 irrigated acreage.

[c] Crop Distribution = Irrigated Acres$_{i,m,2001}$/Total Irrigated Acres$_{i,m,2001}$. i = corn, cotton, peanut, soybean, and other; m = counties in study area.

[d] Simultaneous simulation assumes that a reduction in irrigated acreage has a direct opposite effect as an increase in irrigated acreage. Sequential simulation assumes producers first optimize their acreage distribution across crops on the basis of changes in expected returns and then apply these revised crop percentages to the new level of irrigated acreage.

a change in total irrigated acreage, corn and peanut are close to unitary: 0.91 and 0.95, respectively. Alternatively, cotton and soybean tend to be more inelastic in their response: 0.45 and 0.57, respectively. The high-valued peanut crop appears to be more responsive to irrigation acreage adoption, with the rotation corn crop following suit.

For government programs, as expected, the peanut quota positively influences peanut acreage and dampens acreage allocated to corn and soybean. Both set-aside programs enhance peanut irrigated acreage, and cotton set-aside also increases corn acreage while depressing its own acreage. However, corn set-aside in the cotton equation does have a significant wrong sign.

Slippage

In estimating changes in water demand from a reduction in irrigated acreage, conventional physical models assume proportional reductions in all crops and do not consider substitution and expansion effects associated with changes in the economic environment. In economic models, changes in water demand are driven by changes in the distribution of crops producers choose to irrigate from year to year, and crop distributions are based on their expected risks and returns, total available irrigated acreage, and possible institutional policy shifts. The difference in water demand estimates from physical and economic models is an estimate of "slippage." This slippage estimate can result in a higher or lower expected water use depending on the effect of relative profitability.

Estimated physical and econometric calculations of crop distributions for the 2001 EPD irrigation reduction program are summarized in Table 4. The "Other" crop is the residual in total irrigated acreage (i.e., the difference between total irrigated acreage and the sum of the four crop acreages—corn, cotton, peanut, and soybean). "Other" constitutes mainly vegetables and orchard crops. The difference in the total acreage between 2000 and 2001 is EPD's estimated reduction of 33,000 irrigated acres.

In both the physical and the econometric models, computations of changes in water demand are calculated on a county basis. For the physical model, the base year (2000) 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. The calculated acreage proportions are then multiplied by the reduction in total irrigated acreage in the county resulting from the EPD auction. These proportional acreage reductions for each crop are then multiplied by the region- and crop-specific BC coefficients to calculate the change in water demand for each crop and county, and these changes are summed up over the counties to give the total estimated 2001 decrease in water demand.

Crop acreages and water demand are simulated by applying the coefficients from Equation (6) to expected risk and return data for years 2000 and 2001. Data for 2000 and 2001 were obtained from the same sources used for the econometric model. Although data on market and government prices and variable costs were available from these sources, yields used in forecasting maintain the same assumptions as in the estimation of Equation (6). Holt's method was used to predict yields for 2000 and 2001, which included representative yields for the previous 6 years.

Under the econometric technique, a change in irrigation capacity or crop prices would result in altering the distribution of the crop mix. Irrigation capacity increased in all years used in the acreage response estimation, however, so a straightforward simulation applying the coefficients from Equation (6) to reduced irrigated acreage implicitly assumes that acreage responses to a unit decrease in irrigation capacity are simply the opposite of those for a unit increase in capacity. Changes in water demand on the basis of this assumption are reported in Table 4 as the "simultaneous" solutions. They were calculated by applying the coefficients from Equation (6) to new expected values of all of the right-hand side variables of Equation (6), including new reduced levels of irrigation capacity.

A second set of simulation results is labeled the "sequential" results in Table 4. These results employ the estimates of acreage responses to changes in expected risks and returns of crops without assuming symmetric independent acreage responses to increases and decreases in irrigation capacity. Under the sequential response, the base level of irrigated acreage (for 2000) is used with the new level of expected risks and returns (for 2001) to estimate the crop acreage distribution. These new crop-mix proportions are then applied to the new reduced level of irrigated acreage to generate the estimates of acreage by crop for calculating water demand. This method precludes a crop-mix response to a reduction in acreage that is independent of the response to changes in expected risks and returns. With no observations for reduced irrigation capacity during the study period, the sequential method independently considers crop-mix and acreage-reduction responses.

The changes in irrigated acreage and crop distribution estimates from Table 4 are used in conjunction with the BC coefficients for a normal weather year to estimate changes in water demand and slippage (Table 5). The differences between the proportional acreage reduction assumption of the physical model and the economically responsive assumptions of the econometric model result in estimated slippage of approximately −19% and −24% for the simultaneous and sequential simulations, respectively. This amount of slippage states the physical technique underpredicts water savings by approximately 58,000 to 75,000 acre-feet per day. Thus, failure to consider the economic substitution and expansion effects has led to erroneous estimates for policy analysis.

Conclusions

In this study, we have 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, policymakers are assuming a certain level of decrease in irrigation water demand as a result of reducing the total irrigated acreage. The decrease in water de-

Table 5. Slippage in Measuring Change in Water Demand, 2000–2001[a]

Crop	Blaney–Criddle Coefficient	Change in Water Demand[b]		
			Econometric	
		Physical	Simultaneous	Sequential
Corn	11.20	−52,189	65,890	64,221
Cotton	11.77	−117,321	−460,183	−523,400
Peanut	6.37	−47,516	−102,627	−92,901
Soybean	7.59	−9,269	112,453	104,947
Other	9.23	−86,215	13,882	59,866
Total		−312,510	−370,585	−387,267
Slippage[c]			−0.186	−0.239

[a] Slippage measure assumes a normal weather year.
[b] Measured in acre-feet (note that one acre-foot equals 325,800 gallons). Physical (econometric) water demand is calculated by multiplying the physical (econometric) crop distribution within a county by the change in total irrigated acreage times the BC coefficient. The physical and econometric county water demands for each crop are then summed over all the counties.
[c] Slippage is equal to one minus the ratio of the econometric change to the physical change in total water demand.

mand is then in turn assumed to benefit both the interstate and intrastate allocation of water from the Flint River. The policymakers 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, policymakers might be better equipped to assess the net change in water demand. Greater precision in information is beneficial, given that the 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. This enhanced water savings of around 19% to 24%, estimated from the econometric model, was the result of a shift in planted acres away from relatively more water-intensive crops, such as cotton, to a more water-conserving crop, peanut. This shift in planted acres was predicated on economic substitution and expansion effects on the basis of changes in expected prices and institutional conditions.

This study paves the path for further research with more sophisticated techniques and precision forecasting. Admittedly, one of the weaknesses of this study is the unavailability of data, especially irrigation data, by crop and by county. For this reason, the study depended on data smoothing by interpolation methods and estimating county-level crop irrigation on the basis of state-level aggregates. Future research could benefit from the use of more frequent irrigation and actual water use data at the county level by crop. More precise policy analysis will thus be possible through the exploitation of interactions between time series and cross section data. The analysis could then be extended by validating the estimates with a comparison of actual crop distributions with the estimated predictions. With this study as a foundation and improvements in data on disaggregated irrigation by crop, a model predicting water saving from reduced irrigation and incorporating economic adjustments could be developed and employed by EPD for accurately estimating their policy effects.

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