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Econometric Forecasting of Irrigation Water Demand Conserves a Valuable Natural Resource

Swagata "Ban" Banerjee and Babatunde A. Obembe

Natural causes (such as droughts), non-natural causes (such as competing uses), and government policies limit the supply of water for agriculture in general and irrigating crops in particular. Under such reduced water supply scenarios, existing physical models reduce irrigation proportionally among crops in the farmer's portfolio, disregarding temporal changes in economic and/or institutional conditions. Hence, changes in crop mix resulting from expectations about risks and returns are ignored. A method is developed that considers those changes and accounts for economic substitution and expansion effects. Forecasting studies based on this method with surface water in Georgia and Alabama demonstrate the relative strength of econometric modeling vis-à-vis physical methods. Results from a study using this method for ground water in Mississippi verify the robustness of those findings. Results from policy-induced simulation scenarios indicate water savings of 12% to 27% using the innovative method developed. Although better irrigation water demand forecasting in crop production was the key objective of this pilot project, conservation of a valuable natural resource (water) has turned out to be a key consequence.

Key Words: acreage allocation, econometric forecasting, expansion effect, institutional change, irrigation, production, substitution effect, water conservation

JEL Classifications: Q12, Q25

Agriculture in many parts of the United States, including the South and Southeast, has been plagued with the nagging problem of limited water supply in recent years (U.S. Geological Survey [USGS], 2012a, 2012b). For example, the aquifer level under the alluvial soil to the immediate east of the Mississippi River (Mississippi River Alluvial Aquifer) has been declining (Yazoo Mississippi Delta Joint Water Management District, 2012). A declining water supply has possibly been made worse as a result of the recent droughts.

Additionally, policies may further restrict use of water for irrigating crops. For example, the long-standing issue of equitably allocating water in the tri-state area of Alabama, Florida, and Georgia prompted auctioning of water among farmers in Georgia a little over a decade ago. Attempting to move toward an efficient water management program within the tri-state area, the Georgia legislature in 2001 passed the Flint

Swagata "Ban" Banerjee is an associate professor in Agribusiness, School of Agriculture, at the University of Wisconsin-Platteville, Platteville, Wisconsin. Babatunde A. Obembe is a former graduate assistant in Agribusiness at Alabama A&M University, Normal, Alabama.

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River Drought Protection Act (FRDPA, 2001). 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. The objective of this auction was to increase the Flint River water flow, which was adversely affected by the 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 Georgia Environmental Protection Division (EPD), a producer would then agree not to use irrigation on the land for the 2001 growing season. After five rounds of auctions, 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 EPD, 2001). Such an increase would aid in mitigating the drought conditions (Banerjee et al., 2007).

Last but not least, the recent interest in alternative fuels may create different crop mixes creating different water demands. Therefore, a method of evaluating the water needs of different crops and the value of water to each crop would provide agricultural producers with valuable information. This motivated us to conduct the Mississippi study and then another study in Alabama (similar to the Georgia study) with surface water in the Alabama–Coosa–Tallapoosa (ACT) and Apalachicola–Chattahoochee–Flint (ACF) river basins.

From a policymaking perspective, decision-makers also need better tools to devise programs and policies to deal with water shortages. However, demand for water is unobservable; hence, it is best studied through crop acreage estimates/forecasts mated with water used/required by the relevant crops. A model that combines a land acreage allocation with the crop- and region-specific water use coefficients (proxy for net irrigation water requirements by crop) was developed to estimate irrigation water demand and hence estimate water value through crop acreage. This acreage response model is based on a portfolio-type analysis that not only incorporates measures of risks and returns, but also allows for agronomic and other influences (Banerjee et al., 2007).

The overall objective of this pilot study was to develop a robust method of better predicting agricultural water demand for irrigating major crops grown in the South/Southeast such as corn, cotton, peanuts, rice, and soybeans.

In particular, the following steps let us fulfill the basic objective of developing such a method of prediction:

1. Develop an econometric modeling system of crop-irrigated acreage responses based on expected prices, expected yields, expected crop returns, variances and covariances of crop returns, and total irrigated acres by crop.
2. Use the acreage forecasts from the estimated econometric model with the relevant actual water use data in Mississippi and Blaney-Criddle coefficients in Georgia and Alabama (U.S. Department of Agriculture–Soil Conservation Service [USDA-SCS], 1970) to estimate water demand by crop and compare and contrast the predicted results from this econometric approach against those from the traditional physical (engineering)[1] approach that uses the initial crop distribution to predict water demand.

   Steps 1 and 2 allowed the estimation of crop-irrigated acreage a year in advance, thus enabling us to calculate the value of water saved in terms of irrigated acreage.
3. From these water demand estimates for the econometric and engineering approaches, use simulated prediction scenarios to determine responsiveness of the econometric approach vis-à-vis the engineering approach to certain economic and institutional variables and calculate slippage, a measure to distinguish between the two approaches. The

[1] The words physical and engineering are used synonymously and interchangeably in this article and related literature to indicate the naïve, simplistic, traditional way of proportionally reducing water allocation across crops over time in the wake of a reduced supply.

value of water saved by differing the crop mix allows the calculation of the value per acre-inch of water on a crop-by-crop basis. Calculation of slippage (one minus the ratio of the econometric change to the physical change in total water demand) enables us to visualize this difference like in related literature (Banerjee, 2004; Tareen, 2001).

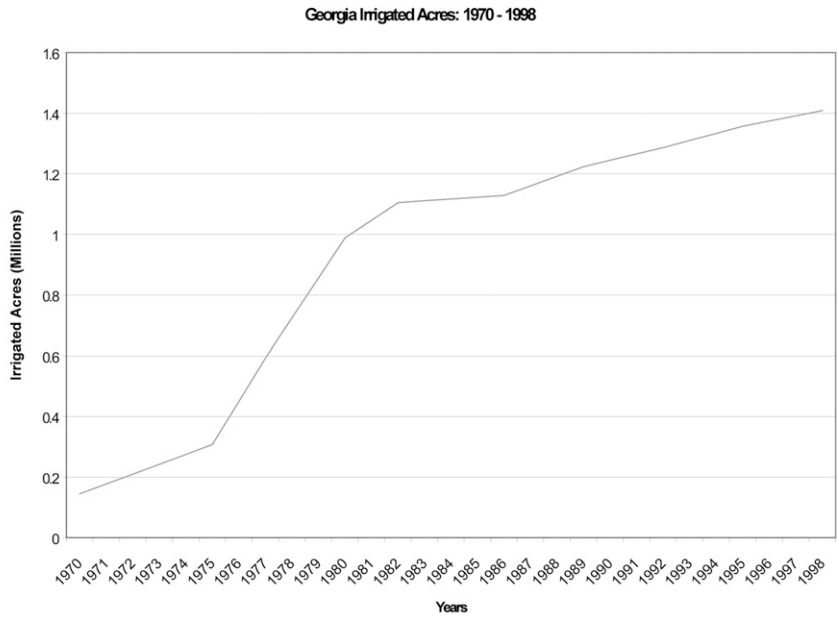
Data and Methods

This article is an initial attempt to combine and compare the three relevant studies in the three different states of the region. The crops studied were corn, cotton, peanut, and soybean for Georgia; corn, cotton, rice, and soybean for Mississippi; and corn and soybean for Alabama. The Georgia and Alabama studies (with surface water) were done at the county level by crop, whereas the Mississippi study (with groundwater) was a state-level study. The Georgia study incorporated 31 Georgia counties approximating the Flint River Basin, whereas the Alabama study used all 34 Alabama counties that jointly serve the ACT and ACF river basins. However, as a result of low acreages in several counties, 17 counties in Georgia and 10 counties in Alabama, respectively, were clubbed as one county called "other" in each of those surface water studies (Banerjee, 2004; Banerjee and Obembe, 2012).

For Georgia and Alabama, irrigated acres data came from the respective Cooperative Extension Services (Georgia: years 1970, 1975, 1977, 1980, 1982, 1986, 1989, 1992, 1995, and 1998 for state and 1974, 1978–1982, 1984, 1986, 1989, 1992, 1995, 1998, and 2000 for county; and Alabama: years 1980, 1984, 1985, 1987, 1988, 1990, 1992, 1996, 1999, 2000, 2002, 2005, and 2007 for state and 1984–1988, 1990, 1992, 1994–1996, 1999, 2000, 2002, 2005, 2005, 2007, and 2009 for county). Data interpolation for the missing values assumed irrigation acreage increased or decreased linearly between two time intervals. This resulted in a time-series of irrigated acreage by crop by county from 1979 through 1998 for Georgia and from 1984 through 2008 for Alabama. In addition, total irrigated acres for Georgia (1970–1998) were collected from U.S. Department of Agriculture - Natural Resources Conservation Service (USDA-NRCS, 1995) (Figure 1). All harvest data came from the U.S. Department of Agriculture - National Agricultural Statistics Service web site (USDA-NASS, 2012: years 1979–1998 for Georgia and 1980–2010 for Alabama).

Price data for Georgia were obtained from the CD-ROM "Historical Futures Data 1959–Present" (Prophet Financial Systems, Inc.) and those for Alabama from the USDA-NASS Application of Futures Prices Forecasting Model. Following Chavas, Pope, and Kao (1983), Choi and Helmberger (1993), Eales et al. (1990), Gardner (1976), and Holt (1999), futures prices were used for all three studies to represent expected prices.[2] Weighted average prices in March for harvest-time futures contracts for corn, cotton, and soybean (December contract for corn and cotton and November contract for soybean) were 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 the USDA-NASS. Peanut price forecasts were then based on a linear lag price regression. Yield data by county and crop were from *Georgia Agricultural Facts* (for Georgia, 1970–2001) and *Alabama Agricultural Statistics* of USDA-NASS (for Alabama, 1980–2011). Historical per-acre variable costs data were obtained from the U.S. Department of Agriculture - Economic Research Service (USDA-ERS, 2012): 1975–2001 for Georgia and 1984–2010 for Alabama. For Georgia, years 2000 and 2001 were chosen for out-of-sample forecasts as the latest irrigated acreage data available for all crops for

[2] In fact, this research experimented with two alternative methods to forecast prices and yields and used the root-mean-squared-error criterion to choose the better option, which turned out to be the one with futures prices and an alternative yield calculation as done by Holt (1999) to include representative yields from the previous six years (Banerjee et al., 2007). Tareen (2001) used only one method—the one using historical data—to forecast prices and yields, and it turned out to perform the worse of the two methods used in this research.



Source: USDA – Natural Resources Conservation Service.

Figure 1. Georgia Irrigated Acreage, 1970–1998

comparison were until 2001. Likewise, years 2009 and 2010 were chosen as out-of-sample forecast years for Alabama.

Data for the Mississippi study were primarily obtained from USDA-NASS (2012) (data on state planted and irrigated acres by crop and yields by crop, 1980–2007; and total irrigated acres, 1982–2002: Figure 2), Commodity Research Bureau (2007) (data on futures prices by crop, 1980–2007), USDA-ERS (2012) (data on variable costs by crop, 1980–2007), and Yazoo Mississippi Delta (YMD) Joint Water Management District (2012) (data on water use by crop, 2002–2007: Figure 3). A time-series for Mississippi starting in 1984 and ending in 2003 was chosen for the sample. Years 2004 and 2005 were chosen for out-of-sample forecasts, because the latest irrigated acreage data available for all crops for comparison were until 2005.

Theoretical Modeling

In keeping with the expected utility theory, a representative farmer is assumed to maximize his or her utility of expected profit (Π_i) and come up with an optimal choice of irrigated acreage (A_i) for each crop:

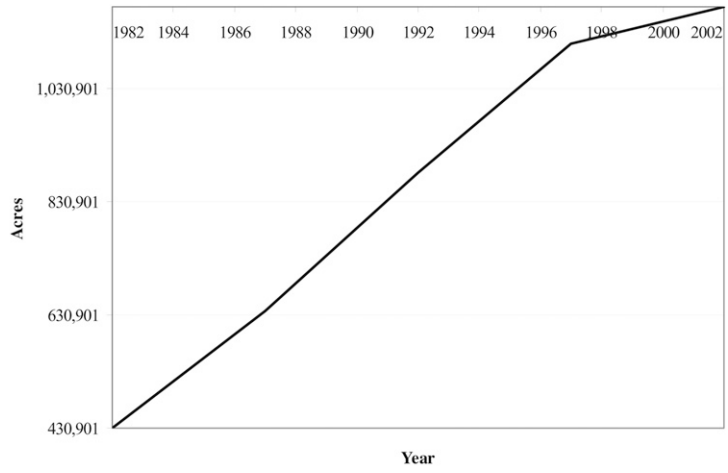
$$A^*_i = A_i(\Pi_j, \sigma_{jj}, \sigma_{jk}, A, \overline{T}, \overline{G}), \quad \forall\, i,j,k = 1,\ldots,n, j>k, \tag{1}$$

where Π_j is the expected profit accruing from the j^{th} crop, σ_{jj} denotes the variance in profit for the j^{th} crop, σ_{jk} the covariance of profit between the j^{th} and k^{th} crops, A is total irrigated acres, $\overline{T}$ is technology, and $\overline{G}$ represents governmental programs.

The vector of covariances accounts for the mechanism of risk spreading by farmers through the portfolio effect. Technology and government programs were considered fixed in estimating the model for Mississippi, corn and cotton set-asides and peanut quota program were used for Georgia, and only the corn set-aside for Alabama.

Empirical Modeling

Step 1. Expected profits and the variances and covariances of expected profits were calculated using futures prices, past yields (Holt, 1999), and covariances between those prices

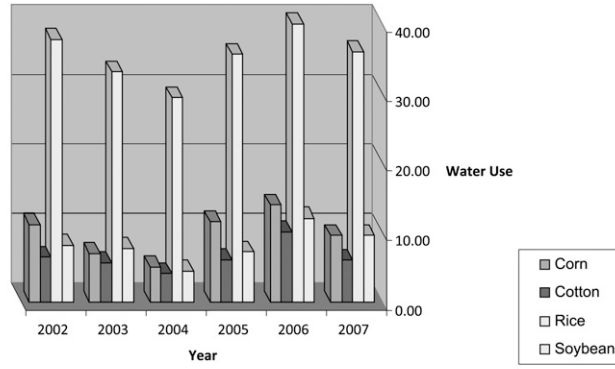


Source: http://www.nass.usda.gov/Statistics_by_State/Mississippi/Search/index.asp.

Figure 2. Total Irrigated Acres, Census Years, Mississippi, 1982–2002

and yields (Bohrnstedt and Goldberger, 1969). The irrigated acres of each of the crops were then linearly regressed on right-hand-side variables including expected profits, variances, and covariances of profits from all crops and total irrigated acres. Furthermore, the Georgia study included three government program dummy variables (corn and cotton set-asides and a peanut quota), and the Alabama study included one government program dummy (corn set-aside). In addition, the Georgia study had 16 county-specific dummy variables as regressors for the 17 counties (including one "other") studied, and the Alabama study incorporated 23 such county dummies for the 24 counties (including one "other") considered. Thus, cross-sectional time-series data for the period 1982–1998 (17 years) for Georgia and 1984–2007 (24 years) for Alabama were analyzed. The state-level time-series data for Mississippi were for the period 1984–2004. This yielded a set of crop acreage predictions for each study.

Given the hypothesis of expected utility maximization and the functional relationship between the optimal irrigated acreage and the components of expected utility in equation (1) (Greene, 1997), the empirical model for optimal irrigated acreage may be estimated with the following econometric model (illustration for Alabama with two crops, one government variable, 24 counties, and 24 years' data):



Source: http://www.ymd.org/pdfs/wateruse/Water%20Use%20Report%202007.pdf.

Figure 3. Water Use, Acre-Inches, Mississippi Delta, 2002–2007 Annual Average

$$A^*_{iyt} = \alpha_i + \sum_{j=1}^{2} \beta_j \bar{\Pi}_{jyt} + \sum_{\substack{j=1 \\ j \neq i}}^{2} \beta_j \bar{\sigma}_{jyt} + \sum_{i=1}^{2}\sum_{j=1}^{2} \delta_{ij} Cov\bar{\Pi}_{ijyt} + \eta_i TIA_{yt} + \sum_{m=1}^{1} \Gamma_m G_{mt} + \sum_{y=1}^{23} \theta_{iy} D_y + \in_{iyt} \quad (2)$$

for i, j, $(i \neq j) = 2$ (crops); 1, ……., 24 (counties); and $t = 1$, ……., 24 (1984–2007), where

A^*_{iyt} = irrigated acreage of the i^{th} crop in the y^{th} county at time t,
α_i = intercept term for the i^{th} equation,
Π_{jyt} = mean expected net return per acre of the i^{th} crop in the y^{th} county at time t,
σ_{jyt} = standard variance of expected profits of the j^{th} crop in the y^{th} county at time t,
$Cov\,\Pi_{ijyt}$ = standardized covariance of expected profits between the i^{th} and j^{th} crops in the y^{th} county at time t, $j \neq i$
TIA_{yt} = total irrigated acres in the y^{th} county at time t,
G_{mt} = government variable (set-aside variable for corn, $m = 1$),
D_y = county-specific indicator variable (dummy), and
$\in_{iyt}$ = stochastic mean-zero random error term for the i^{th} equation.

For the sake of easy comparison, the symbols used in the acreage allocation models by Banerjee (2004), Banerjee et al. (2007), Chavas, Pope, and Kao (1983), and Holt (1999), and Tareen (2001) have more or less been maintained in equation (2).

Step 2. Irrigated acreage forecasts obtained from the acreage allocation equations were used with the Blaney-Criddle (BC) coefficients in the cases of Georgia and Alabama and actual water use data in the case of Mississippi, available from obtaining the current and future water demand estimates. Specifically, predicted acreage times the relevant BC or water use coefficient (2002–2007 annual average water used by each crop in the case of Mississippi) equaled the average annual water demand in acre-inches for each crop.

Step 3. By varying some of the economic and institutional parameters, the responsiveness of irrigated acres was determined. Specifically, once the base simulation was created at the end point within the sample, several types of simulations were conducted out of the sample to determine how our model compared with the physical model. This was done by altering prices, yields, costs, and total irrigated acres to reflect out-of-sample data for two consecutive years (e.g., 2004 and 2005 in the case of Mississippi and 2009 and 201 in the case of Alabama). One such simulation assumed an institutionally forced reduction of total available irrigated acreage by 50,000 acres for the Mississippi study and 25,000 acres for the ongoing Alabama study. The resulting water demand estimates obtained by our econometric approach were compared and contrasted with the conventional alternative (physical/engineering) approach through the calculation of slippage. This provided insights into the appropriate model for forecasting crop acreage and hence for forecasting agricultural water demand (Tables 1–3).

In addition, as an out-of-sample forecast, prices projected by Food and Agricultural Policy Research Institute (FAPRI, 2012) for 2016 were used to forecast water demand through irrigated acreage predictions for the Mississippi and Alabama studies (the same for the Georgia study used FAPRI prices projected for 2010). Based on this simulation, the conventional engineering approach was compared with the econometric approach developed.

Results

Assuming the error terms were independently and identically distributed, and the right-hand-side variables were the same for all crops in each study, allowed estimating equation (2) by ordinary least squares (Greene, 1997). All equations (e.g., corn, cotton, peanut, and soybean in Georgia), each with n observations (e.g., $n = 289$ in Georgia: 17 years and 17 counties), were 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

Table 1. Slippage in Measuring Change in Water Demand,[a] Georgia, 2000–2001

Crop	Blaney-Criddle (BC) Coefficient	Change in Water Demand[b]	
		Physical	Econometric[c]
Corn	11.20	−52,189	64,221
Cotton	11.77	−117,321	−523,400
Peanut	6.37	−47,516	−92,901
Soybean	7.59	−9,269	104,947
Other	9.23	86,215	59,866
Total		−312,510	−387,267
Slippage[d]			−0.239

[a] A normal weather year was assumed in calculating slippage as reported.

[b] Measured in acre-feet (note that one acre-foot equals 325,800 gallons). Physical (econometric) water demand was 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 were then summed over all the counties.

[c] Two econometric measures were computed: simultaneous (one that changed risks and returns simultaneously with total irrigated acres) and sequential (one that changed risks and returns subsequent to reduction in total irrigated acres). Only the sequential measure is reported here for matters of comparison. This measure assumed that producers would respond to a decrease in irrigation capacity by optimizing their base acreage allocation in response to changes in expected risks and returns of each crop and then applying the new allocation proportions to the reduced level of irrigation capacity (Banerjee, 2004). The total change in water demand forecast using the simultaneous measure turned out to be −370,585 and slippage −0.186 (Banerjee et al., 2007).

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

dummy variables. The *F*-test statistic for each acreage equation in each state was significantly different from zero at the 1% level. This suggests a strong rejection of the null hypothesis that all parameters except the intercept were zero.

Georgia

The coefficients of determination, R^2, for the corn, cotton, peanut, and soybean equations were 0.94, 0.93, 0.99, and 0.84, respectively. Approximately 50% of the county dummies in Georgia were significant (Banerjee et al., 2007).

Table 2. Slippage in Measuring Change in Water Demand,[a] Mississippi, 2005–2006

Crop	Water Use[b]	Change in Water Demand[c]	
		Physical	Econometric
Corn	9.70	33,012	118,116[d]
Cotton	6.40	112,188	−27,104
Rice	35.34	289,225	−485,154
Soybeans	8.18	−170,825	−361,668
Total		−605,250	−755,810
Slippage[e]			−0.249[f]

[a] Change in water demand is measured in acre-inches (1 acre-inch = 27,150 gallons).

[b] Measured in acre-inches per acre, based on 2002–2007 annual average (YMD Joint Water Management District, 2012).

[c] Change in physical (econometric) water demand = physical (econometric) crop distribution times the change in crop-irrigated acreage times the relevant water use coefficient. Crop distribution assumes no other major users of water. The only other major water user in the state of Mississippi is catfish, but it has not used groundwater every year in the period 2002–2007 (YMD Joint Water Management District, 2012).

[d] A positive (negative) change indicates an increase (decrease) in water demand.

[e] Slippage = 1 – (econometric change in water demand/physical change in water demand).

[f] Slippage using Food and Agricultural Policy Research Institute (FAPRI) 2016 price projections ($2.99/bushel for corn, $0.60/lb for cotton, $8.87/cwt for rice, and $6.37/bushel for soybeans) turned out be a very close 0.248.

Mississippi

Respective R^2 values for the corn, cotton, rice, and soybean equations were 0.92, 0.95, 0.96, and 0.91, respectively. Approximately 50% of the variables were significant, and approximately 80% of the significant variables had their expected signs. Perhaps the most interesting result emerging from the irrigated acreage model was that the expected profit of cotton in its own equation was negative and significant, indicating that cotton producers tended to shift cotton acres out of irrigation and into dry land, reducing the percentage of irrigated cotton when expected profit from cotton production went up and vice versa (Banerjee and Obembe, 2012).

Alabama (*most recent, ongoing study*)

The coefficients of determination, R^2, for the corn and soybean equations were approximately

Table 3. Slippage[a] Comparison of Economic Sequential and Simultaneous Simulations under Three Different Price Situations in Measuring Change in Water Demand,[b] Alabama

Expected Price		Simultaneous (effects[a] together)	Sequential (effects[a] separated)
2010 (futures)	Normal	−0.120	−0.225
	Dry	−0.124	−0.225
2011 (futures)[c]	Normal	−0.221	−0.266
	Dry	−0.220	−0.263
2016 (FAPRI[d] raw)	Normal	0.215	0.150
	Dry	0.219	0.155

[a] Slippage = 1 – (econometric change in water demand/physical change in water demand).

[b] These are preliminary results for effects of changing expected returns and total irrigated acreage (TIA).

[c] The 2011 futures prices for corn and soybeans were preliminary data available during the time of this research.

[d] Food and Agricultural Policy Research Institute.

Note: Slippage under the scenario with expected returns updated and no TIA change cannot be calculated because the divisor (change in engineering irrigated acres) will be zero, because in the context of this study, engineers do not consider a change in crop acres distribution based on price changes. The 2010 and 2011 cases depicted in this table are essentially the scenario with expected returns updated and TIA reduced by 25,000 acres, and the 2016 case is the scenario with expected returns updated with FAPRI prices and TIA reduced by 25,000 acres.

0.86 and 0.82, respectively, indicating the regressors in each of the models explained 86% and 82%, respectively, of the variation in irrigated acreage of the corresponding crop. Sixty-three percent of county dummies in Alabama were significant with expected signs.

In each of the three studies, once the water demand forecasts were estimated from the acreage forecasts, a base scenario in the year immediately after the in-sample forecasts was established based on which of several different simulations were conducted (Banerjee, 2004; Banerjee and Obembe, 2012; Banerjee et al., 2007) and slippage (one minus the ratio of the econometric change to the physical change in total water demand) calculated to compare predictions by the traditional physical measure and the econometric measures developed by us. Because the Alabama study is still ongoing, and for the sake of brevity, only the scenario concerning a forced reduction in irrigation capacity (total irrigated acres) is discussed below through an illustration of the Mississippi study.

Reduction-in-Irrigation-Capacity Scenario

Assuming there was a 50,000-acre policy-induced decrease in irrigation in 2006 over 2005, the differences between the physical and econometric models would result in an increase in water savings by approximately 25% as measured by slippage by shifting water out of irrigation from rice and soybeans into corn and cotton (Table 2). The same for a policy-induced 33,006-acre reduction (FRDPA, 2001) in Georgia was between 19% and 24%, depending on if acres were reduced simultaneously with prices or sequentially like in the Mississippi study (Banerjee et al., 2007; Table 1). Preliminary results of the corresponding study in Alabama showed water savings between 12% and 27% (Table 3).

Using 2016 FAPRI price projections ($2.99/bushel for corn, $0.60/lb for cotton, $8.87/cwt for rice, and $6.37/bushel for soybeans) in Mississippi, the slippage was also approximately 25% with all the directional impacts (shifts in water demand) of relevant crops as shown in Table 1 and hence not reported. The FAPRI projections use ending stock prices, and the projections for all the crops under study were not different enough to illustrate a greater change in the difference between the two approaches than already illustrated using 2006 prices. However, with higher prices resulting in a major shift in acres from cotton and other crops to corn in 2007 and 2008, this percentage of water saved could be presumed to be more pronounced for a study using updated commodity prices.

Summary, Conclusions, and Implications

A major contribution of this pilot research is incorporating substitution effects through price changes along with expansion effects through total irrigated acreage changes in a producer's acreage allocation decision. Producers' decision-making process is primarily based on the expected net returns from the competing enterprises. Probably as a result of lack of evidence in

Table 4. Net Irrigation Requirements (acre-inches) in Normal and Dry Years by Crop and Region of the ACT/ACF[a] River Basins as given by Blaney-Criddle (BC) Coefficients

Crop		Lower[b]	Middle[c]	Upper[d]	Wtd. Avg. (L, M, U)[e]
Corn					
	Normal year[f]	10.43	10.85	11.32	11.52
	Dry year[g]	11.16	12.65	7.05	12.55
Soybeans					
	Normal year	5.55	7.12	5.48	5.64
	Dry year	7.06	8.95	7.93	8.62

Source: Alabama Irrigation Guide, USDA – Soil Conservation Service (1970).

[a] Alabama–Coosa–Tallapoosa/Apalachicola–Chattahoochee–Flint.

[b] Lower ACT/ACF consists of the following Alabama counties: Autauga, Baldwin, Barbour, Bullock, Butler, Clarke, Dallas, Henry, Houston, Lowndes, Monroe, Montgomery, Perry, and Wilcox.

[c] Middle ACT/ACF consists of the following Alabama counties: Bibb, Chambers, Chilton, Coosa, Elmore, Lee, Macon, Russell, Shelby, and Tallapoosa.

[d] Upper ACT/ACF consists of the following Alabama counties: Calhoun, Cherokee, Clay, Cleburne, DeKalb, Etowah, Jefferson, Randolph, St Clair, and Talladega.

[e] The weighted averages of the lower, middle, and upper ACT/ACF river basin regions were calculated based on the weights defined by the percentage distribution of irrigated acres of a given crop in each region.

[f] A normal year is defined as a growing season with average rainfall of 50, 52, and 55 inches of rain in lower, middle, and upper ACT/ACF river basin regions, respectively.

[g] Dry year is defined as a drought on the magnitude of 20% or an average of the 2 driest years in a 10-year period over the last 30 years of weather data.

Note: Conversion rate: 1 ac-in = 27,150 gallons per day. 1 ac-ft = 325,800 gallons per day.

favor of risk aversion coupled with price supports afforded by the government, the focus in the literature thus far has primarily been on the first moments of an expected utility function with minimal regard for the riskiness of competing crops. In the context of a farming enterprise, the first moments are expected returns. However, along with expected returns, this pilot study included a risk-averse farming enterprise's regard for risks associated with each crop as well as with its substitutes and complements as given by the second moments of expected returns, viz., variances and covariances of expected returns.

Through comparing two economic simulations against an engineering simulation for each of three different scenarios (according to different expected returns and total irrigated acreage [TIA] situations), this study attempted to identify the distinction between the conventional water use model and the modern economic model. Furthermore, two different versions of the economic model (simultaneous and sequential) were studied and compared. This gave us the choice of a better technical method in the presence of declining irrigation capacity. Incorporating price and cross-price effects in the acreage allocation decision led to slippage in the measurement of water demand.

The pitfalls associated with disregarding the updated irrigated acreage allocation by crop and by county are clearly established through this research. The model development and the simulation exercises provided insights into the importance of economic theory in the estimation and forecasting of water use. Moreover, it paved the path for further research with more sophisticated techniques and precision forecasting. Under a reduced acres scenario, the overall model developed in this research will aid environmental, natural resource, and land allocation policy specialists to better assess the impact of a change in irrigation capacity on irrigated acres and irrigation water demand for the future on a crop-by-county basis.

As a result of reducing the TIA, policymakers have been anticipating a certain level of decrease in irrigation water demand. The decrease in water demand is then, in turn, assumed to benefit both the interstate and intrastate allocation of water (e.g., from the ACT/ACF river basins in the case of surface water for Georgia and Alabama). With decreased demand,

policymakers anticipate increased water flows for Alabama and Florida as well as more water for the competing users within the state of Georgia.

This research has its strengths over previous studies in that it improved on the engineering approach used to predict water demand. The engineering approach cannot change the crop mix in any year beyond the base year, whereas our economic approaches can do so according to the new predicted acres.

Furthermore, it is an improvement over Tareen's (2001) work in several aspects. First, it uses forecast errors instead of means to calculate covariances between prices and yields to capture risks involved in the calculation of expected profits and to calculate the higher moments (variances and covariances) of expected profits. This is theoretically superior because the risks the farmer faces are risks from inaccurately forecasting prices and yields (and hence returns) rather than the variability of returns around their means.

In addition, the sequential-simulation method adopted in the current study considers a change in expected returns and a decrease in TIA in sequence, thus offering an alternative way of modeling the farmer's response to reductions in TIA, which may be superior to simply assuming that farmers respond to decreased TIA by just doing the opposite of what they would do with an increase in TIA. Previous literature, including Tareen (2001), considered a single economic approach to contrast against the traditional engineering approach. Thus, our current study improves on that front as well.

However, one of the weaknesses of this study has been the unavailability of data, especially irrigation data, by crop and by county. For this reason, we had to depend on data smoothing by interpolation methods. Future research could benefit from the use of more frequent irrigation and actual water use data at the county level by crop (the water use data were available for only Mississippi and BC water use coefficients were used as proxies for Georgia and Alabama). More precise policy analyses will thus be possible through the exploitation of interactions between time-series and cross-section data.

If policymakers can provide data on water use by crop and county each year, economists might be able to improve on the BC coefficients indicating net irrigation water requirements and obtain better water demand estimates. Data on irrigated acreage, water use, and BC coefficients for other (minor) crops would also improve accuracy.

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Appendix

Mathematically, under usual notations followed in the main text, water demand (WD) estimates in the ATC/ACF river basins (Alabama study) by county (y) and crop (i) for the base 2009 simulation and for the 2010 engineering simulation can be shown, respectively, as:

$$\begin{aligned} \mathrm{WD}_{y,2009} &= \sum_{i=1}^{5} \left\{ A^*_{i,y,2009} * BC_{i,y} \right\} \\ &= \sum_{i=1}^{5} \left\{ \left[A^*_{i,y,2009} / TIA_{y,2009} \right] \right. \\ &\quad \left. * TIA_{y,2009} * BC_{i,y} \right\} \end{aligned} \tag{A.1}$$

and

$$\begin{aligned} WD^{ENG}{}_{y,2010} = \sum_{i=1}^{5} \left\{ \left[A^*_{i,y,2009} / TIA_{y,2009} \right] \right. \\ \left. * TIA_{y,2010} * BC_{i,y} \right\}, \end{aligned} \tag{A.2}$$

where TIA = total irrigated acres and BC = Blaney-Criddle coefficient.

The economic approach developed in this study is based on econometric modeling and can easily renew the crop distribution to reflect the new prices and thus take into consideration the substitution effect among crops. The economic approach is more sophisticated than the engineering approach in the sense that it recognizes that the farmer may alter his or her portfolio at any point in time beyond the sample in response to changing economic conditions. The two versions of the economic simulation models differ with respect to how producers are assumed to allocate their irrigation acres to different crops when TIA is reduced. During the estimation period, TIA increased monotonically. Including $TIA_{y,t}$ as an independent variable in each crop-specific acreage equation accounts for the impacts of increases in total irrigated acres on individual crop acres in addition to responses to changes in expected returns and risks for each crop. Allocation of additional irrigation acres to each crop, assuming constant returns and risks in the current period, would theoretically be based on marginal returns and risks of assigning new irrigation capacity to each crop, on agronomic considerations (e.g., rotational possibilities), and possibly on equipment capacity and field size. The estimated coefficients of $TIA_{y,t}$ measure the responsiveness of acreage of each modeled crop to a 1-acre increase in total irrigated acreage, *ceteris paribus*.

Assuming there was a decrease in TIA in 2010 in the ACT/ACF river basins in the Alabama study (in keeping with the fact that the Flint River

Drought Protection Act of 2000 resulted in a decrease in TIA in 2001), any irrigation water planning model should indeed be capable of simulating decreases in water availability. Without historical data on responses of acreage to irrigation capacity decreases, however, there is no empirical basis for modeling such a response. For this reason, we use two alternative assumptions to simulate acreage responses to reduction in irrigation capacity: one, the sequential assumption, and two, the simultaneous assumption.

In the sequential (SEQ) economic simulation model, the base 2009-level of TIA in Alabama, for example, is used with the new level of expected returns and risks, for 2010, to estimate the proportion of irrigated acres that would be allocated to each crop given expected changes in returns and risks. Under this simulation method, these crop acreage proportions are then applied to the new reduced level of TIA to generate the estimates of acreage allocations for calculating water demand. This SEQ method thus assumes that producers respond to a decrease in irrigation capacity by optimizing their base acreage allocation in response to changes in expected risks and returns of each crop and then applying the new allocation proportions to the reduced level of irrigation capacity.

An alternative economic simulation model, referred to as the simultaneous (SIM) model, simply includes the new, reduced level of TIA in the acreage allocation simulation simultaneously with the new levels of expected returns and risks. This version of the simulation thus assumes that the impact of a 1-acre decrease in TIA on each crop acreage is simply the opposite of the effect of a 1-acre increase in TIA as measured by the relevant estimated coefficient of TIA in equation (2).

The base year water demand estimate is the same for the engineering (ENG) and both economic simulations (SEQ and SIM) and is as shown in equation (A.1).

The sequential economic model water demand estimates by county for the 2010 simulation can be shown as:

$$WD^{SEQ}{}_{y,2010} = \sum_{i=1}^{5} \left\{ \left[\left(A^{*}_{i,y,2010} \middle| TIA_{y,2009} \right) \Big/ TIA_{y,2009} \right] * TIA_{y,2010} * BC_{i,y} \right\}. \tag{A.3}$$

The simultaneous economic model water demand estimates by county for the 2010 simulation can be shown as:

$$\begin{aligned} WD^{SIM}{}_{y,2010} &= \sum_{i=1}^{5} \left\{ \left[\left(A^{*}_{i,y,2010} \middle| TIA_{y,2010} \right) \Big/ TIA_{y,2010} \right] * TIA_{y,2010} * BC_{i,y} \right\}, \\ &= \sum_{i=1}^{5} \left\{ \left[A^{*}{}_{i,y,2010} \middle| TIA_{y,2010} \right] * BC_{i,y} \right\} \end{aligned} \tag{A.4}$$

An alternative economic simulation model, referred to as the simultaneous (SIM) model, simply includes the new, reduced level of TIA in the acreage allocation simulation simultaneously with the new levels of expected returns and risks. This version of the simulation thus assumes that the impact of a 1-acre decrease in TIA on each crop acreage is simply the opposite of the effect of a 1-acre increase in TIA as measured by the relevant estimated coefficient of TIA in equation (2).

The base year water demand estimate is the same for the engineering (ENG) and both economic simulations (SEQ and SIM) and is as shown in equation (A.1).

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The simultaneous economic model water demand estimates by county for the 2010 simulation can be shown as:

$$\begin{aligned} WD^{SIM}{}_{y,2010} &= \sum_{i=1}^{5} \left\{ \left[\left(A^{*}_{i,y,2010} \middle| TIA_{y,2010} \right) \Big/ TIA_{y,2010} \right] * TIA_{y,2010} * BC_{i,y} \right\}, \\ &= \sum_{i=1}^{5} \left\{ \left[A^{*}{}_{i,y,2010} \middle| TIA_{y,2010} \right] * BC_{i,y} \right\} \end{aligned} \tag{A.4}$$

where $[A^{*\prime}{}_{i,y,2010} | \ TIA_{y,2009}]$ and $[A^{*\prime}{}_{i,y,2010} | \ TIA_{y,2010}]$ are estimated irrigated acreages of each crop in 2010 given year 2009 TIA and year 2010 TIA given the 25,000-acre reduction, respectively.

Summing irrigated acres by crop across all 24 counties (including the "other" county) in Alabama gives us the sum total of irrigated acres by crop for the three scenarios. Similarly, summing water demand across all 24 counties (including the "other" county) gives us the sum total of water demand by crop for the three scenarios, respectively (equations [A.1–A.4]). Summing across counties in equation (A.1) provides the total base year 2009-level water demand by crop for both normal and dry years. Net irrigation requirements in acre-inches for both normal and dry years by crop and region (upper, middle, and lower) of the ACT/ACF river basins, as given by BC coefficients, are depicted in Table 4.