Effect of Water Price on the Multicrop Production Decision: Appling Fixed Allocatable Input Model in Georgia

By

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Abstract:

This study applies the fixed allocatable input model to test the effect of water price on the multiple production decision in Georgia, U.S. The limited dependent variable models are applied and intensive data are analyzed in this study to estimate the decision for crop choice, land allocation, product supply, and water demand functions at crop-level. In order to investigate the effect of water price on crop-level demand, the total water price effect on farm water demand is decomposed the intensive margin and extensive margin.

Key words: Multioutput production, Water price, Water demand, Limited dependent model

Introduction:

The agricultural sector accounts for about 16 percent of Georgia's $350 billion annual economic output (Georgia Farm Bureau, 1998). It is also often cited as the primary consumptive water user in Georgia. There is, however, considerable uncertainty about how water consumption is distributed across space, time, and crops. Crop choice decisions, affected by economic variables and available input (land, labor, technology, etc.) often influence water use in agricultural production. As the pressure on Georgia's water resources increases, a greater understanding of how water use decisions are made within the agricultural community will facilitate the development of water policy that can protect and enhance the economic integrity of the state's agricultural sector.

One strategy for realizing efficiency gains in water use is through improved irrigation technology and water management at the farm-level. This involves consideration of crop water requirements, irrigation technology, economic factors, and weather variables. These factors simultaneously influence the timing and amount of water applied to agricultural fields and consumed by the agricultural sector.

The econometric evidence on the role of input-use adjustments to higher water prices was formed in the last decade. Previous research in this area studied the price elasticity of demand for irrigation water; quantified the effect of water price to choice of irrigation technique; estimated the effect of a reduced water entitlement on cropland allocation decisions of Reclamation-served irrigators (Moore, etc.). Their findings indicated that the producer will adjust irrigation rationally responding to the signal of water scarcity. However, models of the influence of (implicit) water prices on land allocation, crop choice and water use in the Southeast are missing from the water demand literature.

Data

Multicrop producers in the analysis are those growing at least two crops among corn, cotton, soybean, and peanuts in Georgia. We use five types of data: Farm and Ranch Irrigation Survey (FRIS) production data, input prices paid and output prices received by farmers, climate and weather information, and soil quality characteristics.

FRIS data

The primary data in this analysis are from FRIS. The survey was conducted in 1984, 1988, 1994, 1998, and 2003. The survey provides the dependent variables (output (y_i), farm land (n_i), irrigation water use (w_i), and the decision of type of crops grown (d_i) by crops) for the analysis. Some independent variables from the FRIS include irrigation technology, water sources and total amount, farm land restriction, and water management practices. The detailed description about the FRIS variables are given in the appendix and Table 1 also gives the full view of the statistics about all variables.

Price data[1]

Input price

The cost of irrigation water is the main components of the input costs. But since the implicit water price is not available, the energy cost of irrigation applied by farmers is served as the proxy of water price assuming the groundwater is the marginal source. For a farmer from the FRIS sample to be included in the analysis they must irrigate with groundwater only or with both groundwater and surface water; groundwater is assumed to be the marginal water source when both sources are used. Energy costs for different fuel sources are computed from farm-level

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[1] All price data applied in the model are normalized and the price of service station unleaded gasoline served as the numeraire.

FRIS data on groundwater pumping depth and pumping pressure using the formula (Gilley and Supalla, 1983, pp. 1785).

$$C_k = P_k (1.3716 / E_k)(L + 2.31 PSI)$$

Where C_k ($/acre-feet) is groundwater pumping cost for fuel type *k*. P_k is the fuel price for fuel type *k*. E_k is the fuel efficiency for fuel type *k*. The fuel types are composed of electricity, natural gas, LP gas, Diesel, and Gasoline. L (feet) is the farm-level average depth to bowls or impellers. PSI (poundes/inch^2) is the farm-level average operating pressure. The fuel price data P_k are collected from State Energy Data 2001 Price and Expenditure Data (U.S. Energy Information Administration, 2001), state-level natural gas city gate price (U.S. Energy Information Administration, 1984-2004), and region fuel price paid from USDA in Agricultural Prices Summary (USDA, 1985; USDA, 1989; USDA, 1995; USDA, 2003). The fuel efficiency E_k is from the Irrigation-Handbooks and manuals-National Engineering Handbook Part (NRCS: National Resources Conservation Service, 1997). The fuel efficiency of diesel, natural gas, LP gas, electricity, and gasoline is 0.23, 0.17, 0.18, 0.66, and 0.17, respectively. In the computation, the overall energy cost can be calculated as the weighted average energy cost by different fuel sources. The irrigated acreages powered by the different types of energy serve as the weight.

Farmer's wage is another important source of input price. Five year's field wages ($/hour) are collected (Georgia Ag Facts, 1985-2004).

Output price

Crop price variables are constructed as expected prices in each year. For corn, cotton, and soybeans, three forecast models are constructed by regressing the planting date's future's price for the harvesting date on the lag of the real price for each crop. All results show the future's market can serve as very good expected price for each of crops. Since there is no future's market for peanuts, the question about how to get the expected price for peanut is arising. If all future's market scheme (accuracy) to reveal the expected price are all the same, the same scheme could apply to peanuts too although there is no real future's market. Now the remained task is to test if all crops' future's market schemes are the same. In order to do that, Chow test need to be applied to test the difference among the different crop's future market. Except for peanut, the result from the Chow test shows that our hypothesis that all crops' future's market schemes are the same is true in 0.01 significant level. So the overall forecasting model is applied to peanut to get the expected price. The real 35 year's time series crop prices data are collected from Georgia Ag Facts (1970-2004). The planting date's future's price for the harvesting date are collected and calculated from the daily CBOT data.

Climate and Weather data

Cumulative Cooling Degree Days (CDD) and Cumulative amount of precipitation served as the variables measuring the variation of the climate and weather change. Two climate variables represent the long run expected weather conditions. They are calculated based on the county level 35 year's daily weather records (NOAA 1970-2004). Two weather variables represent the real weather conditions for the corresponding years during the different crop's growing season. They are calculated based on the county level 5 year's daily weather records during the growing seasons (NOAA, 1984, 1988, 1994, 1998, 2003). CDD measures the hot season. The higher CDD means the hotter season. It is calculated as following:

$$CDD = \Sigma \quad \max\left(\frac{T_{\max} + T_{\min}}{2} - T_{base}, 0\right)$$

Where $T_{\max}$ is the daily maximum temperature, $T_{\min}$ is the daily minimum temperature, $T_{base} = 72F^{0}$ in our study.

Soil quality data

Soil quality variables are average county values from the 1988 Natural Resources Inventory conducted by the Soil Conservation Service, USDA. Dummy variables to indicate the good quality of soil and bad quality of soil are calculated from the average county-level soil class. County-level soil class is calculated by weighted average. The corresponding acreage for each soil class serves as the weight.

The detailed explanations of all variables are provided in the appendix. And the statistical descriptions of the corresponding main variables are listed in Table 1.

Model

In this study, a multioutput profit function with land and surface water as fixed inputs will be developed. This problem can be expressed as the following constrained optimization problem

$$\Pi(\mathbf{p},\mathbf{r},b,N;\mathbf{x}) = \max_{n1\ldots n_m} \{\sum_{i=1}^{m} \pi_i(p_i,\mathbf{r},b,n_i;\mathbf{x}) : \sum_{i=1}^{m} n_i = N\} \qquad (1)$$

Where i=1,...,m number of crops grew; **P** is the crop price vector; p_i is the price of crop i; **r** is the input price vector expect for water price; b is water price; $\sum_{i=1}^{m} n_i = N$ land constraint; **x** is the vector of other variables exogenous to the farm or crop(climate, weather, soil quality, and irrigation technology), $\Pi(\mathbf{p},\mathbf{r},b,N;\mathbf{x})$ is the multioutput profit function; $\pi_i(p_i,\mathbf{r},b,n_i;\mathbf{x})$ is the crop-level restricted profit function for crop i. The notations in the following equations are consistent.

Given the normalized quadratic profit function used in the study, the $n_i^*(\mathbf{p},\mathbf{r},b,N;\mathbf{x})$ solved from (1) are linear in the exogenous variables expressed as equation (2). Applying Hotelling's lemma and Envelope theorem to

$\Pi(\mathbf{p},\mathbf{r},b,N;\mathbf{x}) = \sum_{i=1}^{m} \pi_i(p_i,\mathbf{r},b,n_i^*(\mathbf{p},\mathbf{r},b,N;\mathbf{x});\mathbf{x})\}$, the product supply function $y_i(\mathbf{p},\mathbf{r},b,N;\mathbf{x})$ and water demand function $w_i(p_i,\mathbf{r},b,n_i;\mathbf{x})$ will be solved as equation (3) and (4) respectively. The crop choice function can be simply expressed as discrete-choice decision equation as equation (5)

$$\text{Land allocation: } n_i^* = \alpha^i + \sum_{j=1}^{m}\beta_j^i p_j + \sum_{v=1}^{z}\gamma_v^i r_v + \delta^i b + \psi^i N + \sum_{s=1}^{t}\eta_s^i x_s \tag{2}$$

$$\text{Crop supplying: } y_i = \theta^i + \sum_{j=1}^{m} k_j^i p_j + \sum_{v=1}^{z}\xi_v^i r_v + \tau^i b + \rho^i N + \sum_{s=1}^{t} v_s^i x_s \tag{3}$$

$$\text{Water demand: } w_i = \mu^i + v^i p_i + \sum_{v=1}^{z} w_v^i r_v + \varphi^i b + \vartheta^i n_i + \sum_{s=1}^{t}\iota_s^i x_s \tag{4}$$

$$\text{Crop growing decision: } d_i = f_i(\mathbf{P},\mathbf{r},b,N,\mathbf{x}) \tag{5}$$

Where d_i in equation (5) is binary variable, which equals to 1 if crop i is grown and 0 if not grown.

After the equation (2), (3), and (4) are obtained, the farm-level water use equation (6) can be easily decomposed in to an intensive margin and an extensive margin as form (6) following.

$$\text{Farm-level water demand: } W = \sum_{i=1}^{m} w_i[p_i,\mathbf{r},b,n_i^*(\mathbf{p},\mathbf{r},b,N;\mathbf{x});\mathbf{x}] \tag{6}$$

$$\text{Decomposing the total effect: } \frac{dW}{db} = \sum_{i=1}^{m}\left(\frac{\partial w_i}{\partial b} + \frac{\partial w_i}{\partial n_i^*}\frac{\partial n_i^*}{\partial b}\right) \tag{7}$$

The first part of the right-hand side of equation (7) is the intensive margin, which can be estimated by φ^i in equation (4). The second part of the right-hand side of equation (7) is the extensive margin. And $\frac{\partial w_i}{\partial n_i^*}$ can be estimated by ϑ^i in equation (4); $\frac{\partial n_i^*}{\partial b}$ can be estimated by δ^i in equation (2).

So the main tasks are reduced to estimate the equations (2) to (5) now. Equation (5) can be estimated with Probit model. Equation (2) and (3) can be estimated with Tobit model. Equation (4) will be estimated with Heckman model.

Results

Table 2 lists the coefficients of the probit model to estimate the crop selection for multicrop planting farmers. According to Table 2, water price does not play the key role to affect the crop's selection. This result is consistent with the survey conducted by University of Georgia in Georgia, where over 80% farmers identified rotational considerations as the first two most important factor in their decision of which crops to plant but only 23% farmers ranked the input costs as the first most important factors (Mullen et.al). In this study, water price is even more neglectable for crop choice compared with the wage, another component of input price. Although they are not significant, three of four crops' coefficients of water price are negative, which means the higher water price decrease the probability to plant the crop. This makes sense. In the meanwhile, the long run temperature measured by the cumulative cooling degree days is the significant factor to affect the crop-choice for each crop.

Table 3 is the Tobit model result for land allocation. Land allocation result shows the substitute effect among different crops with water price. Higher water price induces the substitution of corn and peanuts acreage for cotton and soybeans. However this substitute effect is not significant in our study. The change of the wage can also induce the substitution effect among the crops due to the different labor requirement for different crops. This substitution effect is more significant compared with the water price. Besides, total available acreage is very significant to affect the land allocation decision and all total acres' coefficients are positive.

Table 4 is the Tobit model result for crop production. Crop production result reveals the similar facts as the land allocation.

Table 5 reports the result of Heckman model to estimate the short-run water demand function. Table 5 shows that water price will significantly affect the short-ran water demand for corn and peanuts. At the same time, except for soybeans, all water price coefficients' sign are negative, which means the higher water price will decrease the demand of the water. This result is strictly consistent the classical micro-economics theory. As for the positive sign in water price's coefficient for soybeans, the water price's effect is closed to 0 and this effect is not significant. So this little violation does not impair the acceptance of the conclusion. As expected, the result shows that the irrigated acreage for each crop plays the significant roles to determine the demand of water irrigated. The more acreage planted, the more water is applied.

Based on the results from Table2 to Table 5, the elasticities with respect to water price can be calculated at the point of means of the corresponding respondent variables and water price. Table 6 reveals that Farm-level responses are highly inelastic in every multicrop strategy decision. Except for the elasticity of short-run water demand for crop corn and peanuts are significant, any other elasticities are not significant at 0.1 significant level. Another important result is that all short-run water demand elasticities are negative[2]. The last important find is that all absolute values of elasticities are very small, implying they are all inelasticity respect to water price in Georgia. The elasticity of crop supply respect to water price for corn even drop to 0. This result is also consistent with the result from UGA survey, where only around 10% respondents will consider the crop water needs when they make the decision to maximize the profit for multi-

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[2] Although the direct Heckman model's coefficient for soybean's short-run water demand is positive, adjusted elasticity based on the adjusted coefficient calculated as in Bockstael et al. is negative.

crops. The similar result is also detected by Moore, Gollehon, and Carey, Nieswiadomy, Ogg and Gollehon, Howitt, Watson, and Adams.

Table 7 shows the step to decompose Farm-level water demand to Crop-level extensive and intensive margins. Firstly, according to the results in Table 7, all responses at the intensive margin outweigh the extensive margin in absolute value. Second, the water price effect on land allocation contributes comparatively less to the extensive margin. Third, all crop-level intensive margins are negative. Fourth, all crop-level total effects on water demand respect to water price are negative. The last one is that the total farm-level water demand respect to water price is negative too. All those findings are reasonable.

Table 1. Statistical Description for Selected Variables

Variable	Mean	Std
FARM-LEVEL VARIABLES		
Number of Farms	784	
Depth	152.25	87.02
PSI	59.63	23.11
Wtrprc	24.06	12.79
Wtrnprc	20.34	10.71
Nwage	5.19	1
Totacr	768.84	785.36
Totwtr	491.62	647.26
Clmcdd	1057.94	89.74
Clmpcp	51.14	3.87
Binary Variable	Percentage(%)	
Dmpres	98.72	
Dmnowt	16.44	
Dmlwmg	11.73	
Dmhgmg	21.81	

CROP-LEVEL VARIABLES	Corn		Cotton		Peanuts		Soybeans	
Number of Farms	544		547		678		219	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Ownacr	257.81	311.15	421.05	435.43	270.36	358.34	223.31	247.9
Crpwtr	197.55	301.31	259.62	366.91	159	245.99	128.51	221.95
Crppdt	37259.48	46401.61	388930.3	418129.6	1010933	1258624	9035.32	9826.94
Crpwtr_acre	0.72	0.48	0.58	0.38	0.58	0.39	0.48	0.32
Crnprc	2.23	0.4	0.57	0.17	0.24	0.08	5.42	1.19
Owncdd	950.5	201.28	1074.69	245.6	1064.68	246.36	1002.58	230.07
Ownpcp	28.59	7.67	30.68	8.41	28.88	7.69	28.66	8.44

Table 2. Probit model for crop selection

Independent variable	Corn	Cotton	Peanuts	Soybeans
crnprc	0.462*	-1.395**	0.871	0.197**
wtrnprc	-0.003	-0.003	0.010	-0.005
nwage	-0.316**	0.513**	-0.018	-0.567**
totacr	0.000	0.000**	0.000*	0.000*
clmcdd	-0.002**	0.001*	0.001*	-0.002*
clmpcp	0.012	-0.046*	0.055*	-0.011
goodsl	0.149	-0.015	0.276	-0.232
badsl	0.330*	-0.576**	0.222	0.309*
dmsrwt	0.005	0.341**	0.137	-0.393**
dmnowt	0.059	-0.414**	0.110	0.178
dmlwmg	-0.083	0.128	-0.012	-0.080
dmhgmg	0.015	0.161	-0.332*	0.229*
_cons	2.940*	-0.094	-3.581*	4.141**

Note: * and ** denote significance at the 0.1 and 0.01 levels respectively in all tables.

Table 3. Tobit model for land allocation

Independent variable	Corn	Cotton	Peanuts	Soybeans
crnprc	77.192*	-204.493**	12.530	5.707
wtrnprc	0.347	-0.957	0.103	-0.514
nwage	-17.559	55.951**	-20.121*	-43.355**
totacr	0.238**	0.435**	0.385**	0.171**
clmcdd	-0.096	0.073	0.117	-0.051
clmpcp	-0.594	-5.441	3.547	-3.280
goodsl	21.949	-0.427	-6.173	3.384
badsl	1.139	-43.359	27.203	22.382
dmsrwt	-52.136*	-2.973	27.650*	-3.657
dmnowt	42.593	0.625	-20.168	30.376
dmlwmg	-7.678	21.800	-23.331	3.146
dmhgmg	-32.994	12.956	4.718	22.192
_cons	117.681	80.531	-242.134	433.350*

Table 4. Tobit model for crop production

Independent variable	Corn	Cotton	Peanuts	Soybeans
crnprc	4996.09	-344468**	-459048*	-288.387
wtrnprc	4.98144	-928.105	421.8303	-29.2114
nwage	-1150.94	42113.34**	-48805.2*	-1849.14**
totacr	36.0727**	418.0054**	1356.849**	7.432051**
clmcdd	-17.5281	116.9865	595.813*	-1.28305
clmpcp	-129.703	-5403.02	16788.18*	-206.681
goodsl	4204.38	19197.64	41040.64	1386.801
badsl	-1163.83	-29635.5	145385.9*	1397.733
dmsrwt	-8726.96*	10714.82	89901.94*	570.2537
dmnowt	4248.72	-32386	-75841.7	661.6652
dmlwmg	1546.28	21227.84	-74908.9	-209.979
dmhgmg	-2198.52	32215.44	53200.09	1480.677
_cons	28578.3	150148	-1248273*	23098.88*

Table 5. Heckman model for short-run water demand

Independent variable	Corn	Cotton	Peanuts	Soybeans
crnprc	11.535	115.630	192.458*	2.622
wtrnprc	-1.403*	-0.811	-0.990*	0.002
nwage	25.630	30.525	20.959*	18.458
ownacr	0.755**	0.692**	0.570**	0.753**
dmsrwt	-14.768	-16.753	-26.205*	4.639
dmnowt	13.372	1.588	-7.386	-19.732
dmlwmg	51.430*	6.318	8.021	-20.126
dmhgmg	0.073	3.573	6.202	-22.657*
dmowntc	-8.271	130.677*	121.509**	36.155
owncdd	0.080	0.145**	0.054*	0.045
ownpcp	-5.333**	-0.942	-1.945*	-0.368
_cons	-28.465	-512.496**	-228.116**	-158.132*
rho	-0.265	0.221	-0.784	-0.514
sigma	160.771	207.053	138.512	77.520
lambda	-42.683	45.668	-108.534	-39.828

Table 6. Elasticities with Respect to Water Price

Crop	Elasticities with Respect to Water Price			
	Crop Choice	Land Allocation	Crop Supply	Short-Run Water Demand
Corn	-0.03	0.03	0	-0.15*
Cotton	-0.02	-0.05	-0.05	-0.06
Peanuts	0.03	0.01	0.01	-0.10*
Soybeans	-0.11	-0.05	-0.07	-0.02

Note:
(1)*denotes significance at the 0.10 level and ** at the 0.01 level on the estimated water price coefficients used in calculating the elasticity values from the respective equations
(2) All elasticities are calculated at the means of the respondent variables and independent variable, Water price.
(3) Short water demand elasticity respect to water price adjusted by the estimated probability the crop is grown and the change in probability of growing the crop given the estimated coefficient (as in Bockstael et al.).

Table 7. Decomposing Farm-level Water Demand: Marginal Adjustments to Water-Price at the Crop-Specific Extensive and Intensive Margins

Crop	$\partial w_i / \partial n_i$	$\partial n_i / \partial b$	$F(x)_i$	Extensive Margin	Intensive Margin $\partial w_i / \partial b$	Total Effect
Corn	0.76	0.35	0.69	0.18	-1.47	-1.29
Cotton	0.69	-0.96	0.7	-0.46	-0.76	-1.22
Peanuts	0.57	0.1	0.86	0.05	-0.76	-0.71
Soybeans	0.75	-0.51	0.28	-0.11	-0.15	-0.26
Farm total						-3.48

Note:

(1) $F(x)_i$ is the share of the sample growing crop i. It is used here as in McDonald and Moffitt to reflect that each crop is grown by only a share of producers in the sample.

(2) Extensive Margin is calculated by $(\partial w_i / \partial n_i) * (\partial n_i / \partial b) * F(x)_i$

(3) Intensive Margin is the estimated coefficient on water price in the short-ran water demand equations adjusted by the estimated probability the crop is grown and the change in probability of growing the crop given the estimated coefficient (as in Bockstael et al.).

(4) Farm total effect $\partial W / \partial b$ is the sum of the crop total effects.

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Appendix

Variable description

FRIS data

Ownacr: Area devoted to crop i (acres)

Totacr: Total farm level area in crop production (acres)

Crpwtr: Water applied to crop i (acre-feet)

Crpwtr_acre: Average water applied to crop i per acre (acre-feet/acre)

Totwtr: Total water use on farm (acre-feet)

Crppdt: Producing amount for crop i

Di: Binary variable indicating availability of crop i on the farm (1 if present and 0 otherwise)

Dmsrwt: Binary variable indicating availability of surface water on the farm (1 if present and 0 otherwise)

Dmpres: Binary variable indicating availability of pressurized irrigation technology (sprinkler or drip) on the farm (1 if present and 0 otherwise)

Dmowntc: Binary variable indicating availability of pressurized irrigation technology (sprinkler or drip) on crop i (1 if present and 0 otherwise)

Dmnowt: Binary variable indicating the farm discontinued irrigation water use long enough to affect crop yields during the growing season (1 if present and 0 otherwise)

Dmlwmg: Binary variable indicating relied on fixed-time water management practices, eg.,water application according to calendar schedule or a water delivery schedule (1 if present and 0 otherwise)

Dmhgmg: Binary variable indicating relied on advanced water management practices, e.g.,commercial scheduling services, media reports on water use, and/or soil moisture sensing devices (1 if present and 0 otherwise)

Price data

Wtrprc: Unnormalized farm-level energy cost of ground water pumping served as water price ($/acre-foot)

Wtrnprc: Normalized farm-level energy cost of ground water pumping served as water price ($/acre-foot)

Nwage: Normalized farm labor wage rate($/hour)

Crnprc: Normalized price of crop i

Cornprc: Normalized corn price ($/Bu)

Cotnprc: Normalized cotton price ($/Lb)

Peanprc: Normalized peanuts price ($/Lb)

Soynprc: Normalized soybeans price ($/Bu)

Climate and Weather data

Clmcdd: Long-run (1970-2004) average base 72 cooling degree-days (degree-days)

Clmpcp: Long-run (1970-2004) average precipitation (inches)

Owncdd: Actual base 72 degree cooling degree-days over the growing season of crop i (degree-days)

Ownpcp: Actual precipitation over the growing season of crop i (inches)

Soil quality data

Goodsl: Binary variable representing soil with relatively less restrictions to use (1 if land class is 2.74 or less and 0 otherwise)

Badsl: Binary variable representing soil with relatively more restrictions to use (1 if land class is 3.5 or greater and 0 otherwise)