VALUE OF IRRIGATION WATER IN THE MIDDLE ATLANTIC STATES: AN ECONOMETRIC APPROACH

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Abstract

Estimation of the economic value of irrigation water is complicated by a lack of data on the price or marginal cost of water. Through econometric estimation of an aggregate total value product function, this paper obtains marginal irrigation water value estimates for the Middle Atlantic region. Additionally, the impact of temperature and soil conditions on aggregate production within the region is estimated. Ridge regression and covariance analysis are employed to deal with problems of multicollinearity and simultaneous equation bias, respectively. Estimates indicate a substantial and growing return to irrigation within the region.

Key words: irrigation, agricultural production, water demand.

The relative scarcity of water in the West has made the study of water in agricultural use predominantly a western activity. However, technical changes in irrigation equipment combined with price increases for crop output and water substitutes in the middle 1970's have made irrigation more profitable in the East. Although the demand for irrigation in the East is well below that in the West, the growth rate in the East is significantly higher. Between 1950 and 1970, the demand for irrigated acres increased approximately 5 percent annually in the East, and less than 2 percent annually in the West (Hanson and Pagano).

Water is certainly more abundant in the East. However, eastern irrigators must compete for water with many other uses stemming from the denser population of the Eastern United States. Although annual average rainfall can adequately supply the major Eastern United States water users, periods of drought are inevitable, the most recent being in 1983. In the future, water shortage may inhibit eastern irrigators, especially if water quality deterioration limits the usable supply. Yet, there is little work in estimating the agricultural demand for water in the Middle Atlantic States.

Studies estimating the economic value of irrigation water have had to cope with the lack of data on the prices and quantities of water. Two approaches have been taken to mitigate this problem. Linear programming has been the most common method of estimating the marginal value of irrigation water (Anderson et al.; Shumway; Young and Gray; Harmon and Whittlesey). An econometric alternative to linear programming was first proposed by Ruttan. This method uses cross-sectional observations on the value of agricultural inputs and outputs and quantities of irrigation water applied to estimate an aggregate agricultural production function. The Ruttan method has been used in various ways (Frank; Beattie et al.). Difficulties in the Ruttan method have been documented by Hoch (1967) and Lynne. To avoid some of these difficulties, a variant of the Ruttan approach is adopted in this analysis.

This paper estimates the marginal value of irrigation water in the East, particularly in New Jersey, Delaware, Maryland, Virginia, and North Carolina; it shows the impacts of exogenous influences such as soil type and climate on production within this region; and it assesses two econometric approaches for dealing with multicollinearity and simultaneous equation bias. Results could most fruitfully be used in conjunction with estimates of the marginal value of water for other users such as industrial, municipal, and residential. In this way, marginal value estimates may be used to study current water policies and proposals for water transfers.

THE PRODUCTION MODEL

The Cobb-Douglas specification is assumed to adequately describe production within the region under investigation. Let the representative farm's production function be:

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$$(1)\ y_i = a_o w_i^{a_1} \prod_{g=2}^{k} x_{ig}^{a_g} \prod_{j=k+1}^{m} e_{ij}^{a_j} \exp(u_i)$$

for k inputs and m-k exogenous variables where:

y_i = total value of crop output sold on ith farm,

w_i = quantity of irrigation water applied,

x_{ig} = expenditure on the gth input,

e_{ij} = quantity of jth exogenous input, and

u_i = the disturbance term where $u_i \sim N(0,\sigma^2)$.

When using aggregate data, specifying inputs in terms of expenditures allows quality differences in the physical units of each factor to be captured. However, expenditure inputs whose associated prices may not reflect true productive value differences should be avoided. For this reason, the value of land and buildings was not included in the production function. Land and building prices tend to be associated with proximity to metropolitan areas.

Inclusion of exogenous factors such as soil and weather conditions allows investigation of the effects of these factors on farm production. Additionally, a variable representing soil conditions can be considered a proxy for land productivity.

The Cobb-Douglas function facilitates comparison with previous irrigation water demand studies. Restrictions implied by the Cobb-Douglas form include: (1) constant and unitary elasticity of substitution, (2) constant output elasticities, (3) constant and elastic own price elasticities of factor demands, and (4) constant and negative cross price elasticities of factor demands. A disadvantage of the Cobb-Douglas specification is the technical complementarity of production inputs implicit in this technology. The problem with this restriction is that it may be incorrect to assume technical complementarity among the factor inputs when exogenous variables are included in the production function. For example, the marginal product of input x_g in equation (1) is:

$$(2)\ MP_g = a_g y/x_g.$$

This marginal product function is always increased by increases in other inputs:

$$(3)\ \partial MP_g/\partial x_m = a_m a_g y/x_m x_g > 0.$$

Thus, it would be inappropriate to include rainfall as an exogenous factor in a Cobb-Douglas production function. Although high rainfall should increase the marginal production of most inputs, it will decrease the marginal product of irrigation water. Thus, the effect of variations in rainfall across regions and over time on the demand for irrigation water is not explored.

TWO ECONOMETRIC PROBLEMS

Multicollinearity can be a serious problem in estimation of production functions, since production inputs tend to vary together. The researcher must choose between unreliable coefficient estimates and bias created by omitting variables.

As an alternative to dropping relevant variables to alleviate multicollinearity, Brown and Beattie used ridge regression. They estimated the marginal value product of irrigation water for 25 counties in California, using both ordinary least squares and ridge regression. The ridge coefficient estimates were superior to the OLS estimates with regard to prior expectations on coefficient signs and magnitudes. Like Brown and Beattie, Frank estimated production functions for 11 regions throughout the Western United States using both OLS and ridge estimation procedures. Again, ridge coefficient estimates appeared superior to OLS estimates. These results give support to the use of ridge regression in production function studies.

Simultaneous interaction among the production, product demand, and factor supply functions can cause correlations between production factors and the production disturbance term. Such correlations contradict the assumptions underlying single equation estimation of production functions and cause single equation estimates of production coefficients to be biased.

The severity of this bias depends on the nature of the inputs and the components of the error term. Suppose the only productive factor is irrigated land. Further, suppose the influence of rainfall is the sole component of the error term. In this case, simultaneous equation bias should not be a problem. Since irrigated land is generally fixed for the production period, variations in rainfall should not be correlated with irrigated land. Now, instead of irrigated land, suppose the factor of production is irrigation water applied. In this case, variations in rainfall would be expected to be correlated with the production factor. Thus, the studies by Ruttan and Beattie et al., which used irrigation land as an input, may be less susceptible, *ceteris paribus,* to such bias than the study by Frank (as well as this study), which used irrigation water as an input. One way to reduce this bias would be to account for interfarm differences through the use of covariance analysis.

STUDY AREA AND DATA

The region under study includes North Carolina, Virginia, Maryland, Delaware, and New Jersey. This region is characterized by relatively few irrigation installations, except for areas of southern New Jersey and the Delmarva penin-

TABLE 1. SELECTED COUNTIES: NUMBER, PERCENT OF CROPLAND IRRIGATED 1978, AND PERCENT GROWTH OF IRRIGATED CROPLAND FROM 1969 TO 1978; FOR FARMS WITH SALES OF $2,500 OR MORE: MIDDLE ATLANTIC STATES, UNITED STATES

Areas	Number of counties analyzed	Percent of cropland irrigated	Percent growth of irrigated cropland
North Carolina	20	1.4	68
Virginia	17	1.0	−4
Maryland	20	1.7	32
Delaware	3	6.5	65
Northern New Jersey ...	4	1.4	12
Southern New Jersey	5	17.7	9

sula of the lower eastern shore of Maryland and southern Delaware. Of the 242 counties within the region, 69 counties with total cropland of at least 35,000 acres per county in 1978 were selected. Additionally, certain counties were excluded because of insufficient data. Table 1 provides data on the distribution and growth of irrigation within the region.

The primary data source for this analysis was the United States Census of Agriculture. Data were collected for the census years of 1969, 1974, and 1978. Additional data on exogenous factors were calculated from county soil surveys and United States Environmental Data Service Climatological Data reports (U.S. Department of Commerce). (More detailed information about these and other data may be obtained from the authors.) Census data analyzed are per establishment by county. Means and standard deviations by county for selected variables are presented in Table 2.

TABLE 2. MEANS AND STANDARD DEVIATIONS FOR SELECTED VARIABLES BY COUNTY: POOLED OBSERVATIONS FROM 1969, 1974 AND 1978 FOR FARMS WITH SALES OF $2,500 OR MORE, MIDDLE ATLANTIC STATES, UNITED STATES

Variable	Unit	Mean	Standard deviation
Crop output[a]	($1,000's)	7,131	7,176
Irrigation water	(acre-feet)	942	1,838
Labor expenditures[b, c]	($1,000's)	1,293	1,209
Fertilizer expenditures[b]	($1,000's)	1,262	1,024
Machinery expenditures[b] ...	($1,000's)	942	621
All expenditures[b, d]	($1,000's)	7,035	5,674
Soil index	-	1.24	1.21
Sum of summer monthly temperatures	(F°)	221	7.78
Farms	No.	644	421

Source: 1969 and 1978 Census of Agriculture, Vol. 1; Parts 8, 20, 26, 30, and 46; County Data; Table 2 (1969); Tables 2 and 3 (1978).

[a] Deflated to 1967 dollars using the index of prices received by farmers.

[b] Deflated to 1967 dollars using the index of prices paid by farmers.

[c] Labor expenditure are expenditures on hired labor and contract labor.

[d] Machinery expenditures are computed as the rental equivalent of the machinery value plus machinery rental expenditures. Rental rate is computed assuming an interest rate of 10 percent.

ESTIMATION PROCEDURES

Three separate estimation procedures were employed: (1) ordinary least squares (OLS), making use of an aggregated expenditure input variable, (2) ridge regression, and (3) a covariance analysis model.

Ordinary Least Squares

The following Cobb-Douglas function in log form was estimated by ordinary least squares using 69 county observations:

$$(4)\quad \log(y/n) = \log(a_{00}) + a_{01}d_{74} + a_{02}d_{78} + a_1\log(w/n) + a_2\log(x/n) + a_3\log(e_1) + a_4\log(e_2) + \theta,$$

where:

y = value of crop output sold ($1,000/yr.),
w = irrigation water applied (acre-feet/yr.),
x = the sum of the following input expenditures ($1,000/yr.): labor; fertilizer; seeds, bulbs, plants, and trees; machinery; other chemicals; and petroleum,
e_1 = a soil index,
e_2 = the sum of the average monthly temperatures for the months of June, July, and August (F°),
d_t = 1 in year t, and 0 otherwise,
θ = the disturbance term is $\sim N(0,\sigma^2)$, and
n = total number of farms in each county.

Dividing the appropriate variables by the number of farms in each county converts the unit of analysis from the county to the 'average' farm within the county. As noted by Hoch (1967), interpretation of results is unclear when the county is the unit of analysis since the farm, not the county, is a relevant decisionmaking unit. In addition, division by the number of farms will mitigate problems caused by differences in county size (Lynne).[1]

The soil index variable is defined as the ratio of all land in "suitable" sandy soils to total cropland for each county. Soil suitability was calculated by excluding rocky, steeply sloping, and eroded soils. Soil sandiness is expected to influence irrigation rates. Sandy soil has low water-holding capacity and generally makes greater water applications profitable. It is ex-

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[1] Additionally, the above model was estimated with the appropriate variables divided by acres of cropland instead of number of farms in an attempt to eliminate effects caused by differences in farm size across counties. Results obtained from these regressions were very similar to those presented in this paper indicating that such differences were negligible.

Table 3. Estimated Ordinary Least Squares Production Coefficients, Mid-Atlantic States, U.S., 1969, 1974, 1978, and Pooled Data

Estimated coefficient	Variable	Year			
		1969	1974	1978	Pooled
$\hat{a}_1$	water	.016	.039	.045	.042
		(.55)[a]	(2.58)[b]	(2.07)[b]	(3.57)[c]
$\hat{a}_2$	all other inputs	.753	.907	1.039	.940
		(7.07)[c]	(10.58)[c]	(9.43)[c]	(14.77)[c]
$\hat{a}_3$	soil	.192	.119	.155	.157
		(4.51)[c]	(3.28)[c]	(3.37)[c]	(6.43)[c]
$\hat{a}_4$	temperature	3.232	3.978	.934	3.361
		(1.28)	(2.64)[b]	(.41)	(2.85)[c]
$\log(\hat{a}_{00})$	constant	−16.773	−20.709	−4.866	−17.786
		(1.24)	(2.57)[b]	(.40)	(2.81)[c]
$\hat{a}_{01}$	1974				−.240
					(3.07)[c]
$\hat{a}_{02}$	1978				−.555
					(6.30)[c]
	R^2	.700	.823	.764	.747

[a] Parenthetic numbers are t-statistics under the null hypnothesis of no association.

[b] Denotes significance from zero with 95 percent confidence.

[c] Denotes significance from zero with 99 percent confidence.

pected that both the soil and temperature variables are positively correlated with crop output value within the region.

Separate models were estimated using undeflated data for 1969, 1974, and 1978, Table 3. Additionally, by pooling the three data sets, a fourth model was estimated using all 207 observations. Year dummy variables (0, 1 format) for 1974 (d_{74}) and 1978 (d_{78}) were included in the pooled model to account for differences over time due to technical progress. All variables expressed in dollar terms were deflated to 1967 prices before pooling, using either the index of prices received or paid by farmers.

Ridge Regression

Ridge regression, as originally proposed by Hoerl and Kennard (1970 a and b), estimates models in the presence of multicollinearity. The idea is to augment the diagonal elements of the correlation matrix of the explanatory variables with an arbitrarily small constant. By doing so, estimated coefficient variances may be reduced significantly at the sacrifice of coefficient bias. Use of the ridge procedure in production models is discussed in Brown and Beattie.

The following function was estimated by ridge regression:

$$(5)\ \log(y/n) = \log(a_{00}) + a_{01}d_{74} + a_{02}d_{78} + a_1\log(w/n) + a_2\log(x_1/n) + a_3\log(x_2/n) + a_4\log(x_3/n) + a_5\log(x_4/n) + a_6\log(e_1) + a_7\log(e_2) + \varepsilon,$$

where in addition to the variables defined after equation (4):

x_1 = fertilizer expenditures ($1,000's/yr.),

x_2 = labor expenditures ($1,000's/yr.),

x_3 = machinery expenditures ($1,000's/yr.),

x_4 = the sum of the following input expenditures ($1,000's/yr.): seeds, bulbs, plants and trees, other chemicals, petroleum, and

ε = the disturbance term $\sim N(0,\sigma^2)$.

Separate models were estimated for each of the 3 years, as well as for the pooled data set, using various values for the augmenting constant k. Year dummy variables for 1974 (d_{74}) and 1978 (d_{78}) were again included in the pooled model. For 1969, 1974, and 1978, only estimates obtained with k = .6 are presented, Table 4. Pooled data were analyzed for k = 0 through k = .6, Table 5.

One problem with ridge regression is the arbitrariness of the selection of k. The procedure employed by Hoerl and Kennard (1970b) increments k until the estimated coefficients "stabilize" as shown in the ridge trace. For lack of a concrete alternative, this subjective method has generally been accepted.

Another problem inherent in ridge regression is the inability to perform simple hypothesis tests on the estimated coefficients. Classical techniques of statistical inference are not applicable to biased estimators.

Covariance Model

OLS and ridge regression parameter estimates may suffer from simultaneous equation bias. Hoch (1962) suggests that a covariance model on the pooled cross section and time series data set may alleviate the problem. This model incorporates dummy variables for each county and each year into the production function model. The estimated model becomes:

$$(6)\ \log(y_{it}/n) = \log(a_{00}) + \sum_{j=2}^{n} a_{j0}d_j + a_{01}d_{74} + a_{02}d_{78} + a_1\log(w_{it}/n) +$$

TABLE 4. ESTIMATED RIDGE PRODUCTION COEFFICIENTS WITH AUGMENTING CONSTANT k = .6: 1969, 1974, 1978 MIDDLE ATLANTIC STATES, UNITED STATES

Estimated coefficient	Variable	Year 1969	1974	1978
$\hat{a}_1$	water	.023	.034	.041
$\hat{a}_2$	fertilizer	.203	.278	.189
$\hat{a}_3$	labor	.118	.081	.113
$\hat{a}_4$	machinery	.005	.237	.247
$\hat{a}_5$	other	.294	.246	.330
$\hat{a}_6$	soil	.111	.088	.099
$\hat{a}_7$	temperature	3.730	3.080	2.392
$\log(\hat{a}_{00})$	constant	−18.375	−14.550	−11.109

$$a_2\log(x_{it}/n) + a_3\log(e_{2it}) + U_{it};$$

$$i = 1,\ldots,69; \quad t = 1969, 1974, 1978$$

for county i and year t, where in addition to the variables defined after equation (4):

d_j = 1 for county j and 0 otherwise, and

U_{it} = a disturbance term $\sim N(0,\sigma^2)$.

Simultaneous equation bias should be reduced in this model. Differences among counties which can cause bias in observed production relationships will now be reflected in the d_j constant terms. The d_j terms will reflect county differences in managerial ability, relative prices, rainfall, and other unaccounted for variables. Due to its constancy through time, the soil variable was excluded from this model to avoid perfect collinearity with the county dummy variables, Table 6.

ANALYSIS OF RESULTS

Estimated Production Functions

The OLS model provides coefficient estimates of the expected sign for all 3 years, as well as for the pooled model except possibly for the signs of the year dummy terms, Table 5. It might be expected that the coefficients of the dummy terms be positive, reflecting technological advancements in management techniques. Alternatively, signs of the dummy coefficients may be reflecting differences in rainfall over time. Of the 3 years studied, average rainfall within the region was greatest in 1969 and lowest in 1974. Some structural change may have resulted after 1969 since estimates of a_1 and a_2 increased and the overall fit, as measured by the R^2 statistic, was somewhat better in the latter 2 years. A Chow test for equality of the regression coefficients over the 3 years resulted in rejection of the null hypothesis of equality of coefficients with 99 percent confidence. The apparent structural change between 1969 and 1974 may have been the result of the extreme changes in agricultural prices experienced in the early 1970's. Lastly, note the positive effect on crop output from the exogenous factors. The estimated coefficient, corresponding to the soil variable, a_3, remained relatively stable and significantly different from zero at the 99 percent confidence level for all four regressions.

Use of ridge regression to combat multicollinearity was clearly demonstrated by the regression results on the pooled data shown in Table 5. With k set equal to zero, labor and machinery estimated coefficients were negative and the grouped expenditures estimated coefficient (a_5) was unreasonably large (near or greater than 1). As small positive values of k were introduced, most of the coefficient estimates were greatly altered. As k increases to approximately .2, all estimates had the expected sign. When k was increased to .6, all estimates had relatively stabilized.

Although application of ridge regression greatly affected most of the estimated coefficients of the pooled model, it had little impact on the estimated irrigation water coefficient. As k increased, the estimated irrigation water coefficient remained relatively stable, decreasing

TABLE 5. ESTIMATED RIDGE PRODUCTION COEFFICIENTS, POOLED DATA: MIDDLE ATLANTIC STATES, UNITED STATES

Estimated coefficient	Variable	Coefficient values k=0	k=.1	k=.3	k=.6
$\hat{a}_1$	water	.042	.041	.038	.035
$\hat{a}_2$	fertilizer	.303	.281	.253	.229
$\hat{a}_3$	labor	−.147	.010	.076	.101
$\hat{a}_4$	machinery	−.894	−.117	.096	.157
$\hat{a}_5$	other	1.248	.590	.376	.289
$\hat{a}_6$	soil	.114	.132	.118	.100
$\hat{a}_7$	temperature	.276	1.922	2.737	2.956
$\log(\hat{a}_{00})$	constant	.128	−8.659	−13.032	−14.192
$\hat{a}_{01}$	1974	.057	−.026	−.034	−.031
$\hat{a}_{02}$	1978	−.052	.006	.029	.036

TABLE 6. ESTIMATING PRODUCTION COEFFICIENTS FOR THE COVARIANCE MODEL: MID-ATLANTIC STATES, UNITED STATES

Estimated coefficient	Variable	Estimate
$\log(\hat{a}_{00})$	constant	.826
$\hat{a}_1$	water	.011 (1.49)[a]
$\hat{a}_2$	all other inputs	.414 (4.61)[b]
$\hat{a}_3$	temperature	.093 (.090)
$\hat{a}_{01}$	1974	−.138 (3.54)[b]
$\hat{a}_{02}$	1978	0.140 (1.89)

[a] Parenthetic numbers are t-statistics under the hypothesis of no association.

[b] Denotes significance from zero with 99 percent confidence.

only slightly. The same relative constancy was exhibited by the estimated soil coefficient.[2]

Since the OLS and ridge estimates of the irrigation water coefficients were similar in magnitude (tables 3, 4, and 5), it might be concluded that the elasticity estimates are relatively accurate. Unfortunately, results from the estimated covariance model do not support this conclusion, Table 6. Estimated coefficients for irrigation water, temperature, and aggregate inputs from this model fell dramatically. This drop in the coefficient estimates may indicate a reduction in simultaneous equation bias. Hoch (1958) has shown that single equation estimation in the context of a Cobb-Douglas production function tends to produce estimated coefficients that sum toward one regardless of their true values, when simultaneous equation bias exists. Movement of the sum of coefficient estimates from the covariance model away from one supports the contention that this bias has been reduced.

Marginal Water Values

The marginal value products of irrigation water are given in Table 7. Values were computed for variables evaluated at their means. All values were converted to 1967 dollars for comparison. OLS and ridge estimates indicate a general trend of increasing water value. The covariance estimate appears to indicate a bias in the OLS and ridge estimates.

These estimates are marginal values of irrigation water applied and not marginal values of all water in crop production (i.e., irrigation water + precipitation and moisture). Marginal values of all water in crop production would no doubt be much lower due to the non-optimal timing of precipitation, especially when the time period under consideration is as long as an entire season. Since irrigation water is a decision variable, its marginal value is of primary interest.

Comparison with Related Studies

Water elasticity estimates derived in this study can only be compared to those obtained by Frank since, of the related production function studies, only Frank used irrigation water as an input. Frank employed OLS and ridge regression to estimate irrigation water elasticities for several regions in the Western United States. The OLS elasticity estimates were inconsistent and often negative and the ridge regression estimates generally ranged from .013 to .047. These results are very similar to results obtained in this study. However, due to the much greater quantities of irrigation water applied in the western regions studied by Frank, water values obtained from his elasticity estimates ranged from only 2 to 10 dollars/acre-foot.

Other attempts at estimating marginal irrigation water values for the Western United States have produced varying results. Linear programming studies of western regions have produced estimates ranging from approximately 0 to 100 dollars/acre-foot.[3] Ruttan, in his comprehensive production function study, did not explicitly estimate marginal irrigation water returns. However, by taking the difference between his marginal value estimates for irrigated and nonirrigated cropland, an approximate marginal value product of irrigation water can be obtained. In general, Ruttan's implicit water value estimates for western regions ranged from 30 to 80 dollars/acre-foot. Brown and Beattie reestimated one of Ruttan's western regions by ridge regression, which lowered the irrigation water value estimate from 77 to 38 dollars/acre-foot.

In contrast to his western region estimates, Ruttan's implicit marginal irrigation water value estimates for regions of the Eastern United States were extremely high. They ranged from approximately 100 to over 1,000 dollars/acre-foot. Results of this study tend to support Ruttan's results of relatively high eastern irrigation water values.

CONCLUSIONS

Marginal water values appear to be greater in the region under study than in most regions of the Western United States. Estimates are much

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[2] Similar responses to increases in k were observed in the single year regressions for 1964, 1974, and 1978.

[3] Not all of these estimates are directly comparable since they are reported in various forms; i.e., some account for delivery costs, some include returns to management, etc.

TABLE 7. ESTIMATES OF THE MARGINAL VALUE PRODUCT OF IRRIGATION WATER IN CROP PRODUCTION FOR THE MID-ATLANTIC STATES, 1969, 1974, 1978 AND POOLED DATA (1967 DOLLARS/ACRE-FOOT)

	Estimate by technique		
Year	OLS	Ridge (k=.6)	Covariance model
1969	$134.74	$239.47	
1974	255.27	219.33	
1978	354.49	321.46	
Pooled data	318.00	265.45	$79.21

greater than those obtained by Frank, but similar to those obtained by Ruttan. High marginal values may be explained by higher marginal costs of irrigation water in the East, or by the absence of an equilibrium, or possibly both. It may be that eastern irrigators use less than the equilibrium level of irrigation, responding slowly to the introduction of new irrigation technology. Below equilibrium, marginal value exceeds marginal cost. The continued greater growth of eastern irrigation may support this contention. However, there are reasons to expect lower marginal irrigation costs in the Western United States. Public irrigation systems in the West often subsidize western irrigators, keeping their marginal water costs low. Also, the marginal capital costs of irrigation are probably lower in the Western United States. The small scale "supplemental" eastern irrigators cannot capture significant economies of scale that may be captured by large scale western irrigators. Huete et al. have shown that large economies of scale with respect to irrigation systems do exist. Additionally, differences in terrain allow western irrigators to employ less sophisticated irrigation systems. Most western irrigators use inexpensive ditch or flood application procedures while eastern irrigators employ primarily sprinkler systems. For example, 92 percent of acres irrigated in the Mid-Atlantic Water Resource Region in 1978 used sprinkler systems compared with the national average of only 37 percent (U.S. Department of Commerce, 1978 Census of Agriculture).[4] Table 7 shows that marginal values are increasing. If this apparent trend continues and is not accompanied by greater marginal irrigation costs, competition for available water supplies within the region may intensify in the future.

This paper has several implications for methods. First, it is apparent that the Cobb-Douglas technology is too rigid to allow for joint inputs of irrigation water and a variable for either rainfall or drought. The connection between the natural input and applications of water is critical, but can only be captured with more flexible functional forms. Further, the natural variability of rainfall makes the study of uncertainty important. Both topics warrant further study.

Finally, other researchers' concerns about the applicability of single equation estimation of production functions for inferring water use parameters are corroborated. The tradeoff between an omission of variables bias and multicollinearity is unavoidable when simple OLS is used for estimating regional production functions. Ridge regression avoids this unwanted tradeoff. However, the ad hoc nature of this procedure is unsettling and introduction of bias prevents statistical inference. Further, results from the estimated covariance model suggest that a significant simultaneous equation bias may exist in single equation estimates. Ideally, ridge regression applied to a covariance model could yield accurate coefficient estimates. Unfortunately, the computational cost of estimating such regressions on a large data set is high and may exceed any possible information benefit. It appears that more accurate estimation of irrigation water use parameters, at a regional level, will require the collection of cost of water data which would allow alternative estimation approaches such as direct input demand or cost function estimation.

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[4] Note that the Mid-Atlantic Water Resource Region defined in the Census of Agriculture is not identical with the region studied in this paper.

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