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THE DETERMINANTS OF IRRIGATION TECHNOLOGY CHOICE

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In recent years declining groundwater tables and increasing energy costs have combined to drive up the cost of water for irrigation and, a fortiori, irrigation with groundwater. Groundwater tables in parts of the southern high plains have declined 40 feet in the past decade while energy costs have increased over 200 percent (Sloggett and Dickason, Sloggett). The farm operator's response to changes in the cost of water can take a variety of forms. In the short run, operators may adjust by altering the water application rate to a given crop mix. In the long run, operators may also alter the crop composition (including a shift to dryland farming), implement sophisticated water management techniques with existing irrigation technology, or adopt more efficient irrigation technology. Water conserving irrigation technology, in which the plant uses a greater fraction of the applied water, is playing an increasingly important role in reducing both energy costs and water use. In two innovative articles on irrigation technology, Caswell and Zilberman (1985,1986) develop a framework for analyzing the economics of technology adoption and estimate the likelihood of adopting various irrigation technologies on a sample of California fruit growers. This paper extends their research with an empirical analysis estimating the determinants of irrigation technology choice using a national sample of irrigators. We apply a discrete choice framework to farm-level data from the 1984 Farm and Ranch Irrigation Survey.

In this study, we consider two broad categories of irrigation technology, sprinkler and gravity irrigation. Sprinkler irrigation saves from 10 to 35 percent of the water applied compared with gravity through increased application efficiency (Caswell and Zilberman (1985), Sloggett, Benami). No effort is made to differentiate among various types of gravity and sprinkler technologies or to examine the use of drip systems. Although the use of drip systems is on the rise, a few specialty crops constitute the bulk of drip irrigated acreage.

In addition to the dichotomous choice of irrigation technology, we estimate the probability of adopting water reuse tail-water pits for those operators who elect a gravity irrigation system. Tail-water pits, by recirculating the run-off from the field, can deliver water savings of 10-30 percent depending on the land topography and soil characteristics.

This study is part of a larger project estimating, econometrically, the demand for groundwater irrigation. The water demand research estimates short-run (intra-season) water demand holding irrigation technology and cropping pattern constant. In the long run (inter-season), both technology choice and land allocation are endogenous. The technology choice equations reported here may be considered reduced form equations of the structural long run water demand and are of significant interest in themselves.

This investigation and the demand estimation focus on groundwater users because they are, by assumption, not quantity constrained and thus allocate water based on price. For groundwater irrigators the marginal unit price of water is the energy cost of pumping the water from the water table. The sample also includes conjunctive users of both ground and surface water by assuming the marginal unit of water for conjunctive users comes from the groundwater source. While the results are technically limited to groundwater users, they suggest the magnitude of the responses of irrigators who face market prices for water. Given the emergence of water marketing and market incentives in water allocation, these estimates will prove valuable in estimating the impact of market pricing on technology choice.

Irrigation technology choice probabilities are estimated using a national cross-section of farm operators who use groundwater for irrigation. Cross-sectional variation in input prices, well depth, weather conditions, topography, and soil characteristics explain which irrigation technology may be more profitably employed. As with most cross-sectional analysis, the observed irrigation technology mix is assumed to be in long-run equilibrium. In general, sprinkler and gravity technologies are not crop specific; except for rice, all crops surveyed on the Farm and Ranch Irrigation Survey reported acreage using both technologies. Since cultivating rice precludes operators from adopting sprinkler irrigation, rice growers are excluded from the sample.

THEORETICAL FRAMEWORK

This model relates the probability of choosing sprinkler irrigation or tail-water pits to the underlying physical and economic attributes of the farm. Farm operators choose, for each acre of land, the irrigation technology that yields the highest quasi-rents subject to variable input prices, expected weather conditions, land topography, soil characteristics, and total irrigated land. The number of observed choices on each farm equals the number of irrigated acres on the farm. The proportion of land using a particular technology then equals the proportion for which that technology is more profitable. Calculating the relative frequency of sprinkler irrigation on the farm produces an unbiased estimate of the probability of the operator choosing sprinkler irrigation for a representative acre.

A binomial logit or probit model is useful for investigating the influences of farm attributes on the technology choice decision, as the probabilities or proportions vary with changes in the exogenous variables. With profit-maximizing behavior, competitive variable input and output markets, and well-defined production technology, the dual profit function is also well-defined when there is a fixed input such as land (Diewert, McFadden, Lau). Let Π_G, Π_S be the variable profit functions under gravity and sprinkler technology, respectively. The farm operator compares the maximum quasi-rent available with each technology and allocates the cropland to the technology yielding greatest profit. The proportion of land allocated to sprinkler irrigation is equal to $\text{Prob}(\Pi_S > \Pi_G)$. Assuming a linear, stochastic form for the profit function,

$$\Pi_t = \beta_t X + \epsilon_t, \qquad t=G,S,$$

where X is a vector of farm-specific price and physical characteristics, β_t is a vector of parameters (to be estimated) for each technology, and ϵ_t is a random error term representing unobserved factors influencing profitability under technology t.

The operator chooses sprinkler technology over gravity where $\Pi_S > \Pi_G$ or equivalently,

$$\beta_S X + \epsilon_S > \beta_G X + \epsilon_G \quad \text{or } \epsilon_G - \epsilon_S < \beta_S X - \beta_G X.$$

Then the probability of selecting sprinkler technology is

$$P_S = \text{Prob}[\ \epsilon_G - \epsilon_S < (\beta_S - \beta_G)X].$$

Let F be the cumulative distribution function of the difference $\epsilon_G - \epsilon_S$, so that $P_S = F[(\beta_S - \beta_G)X]$.

If ϵ_G and ϵ_S are independent of X and are distributed independently Weibull, the cumulative distribution function, F, generates the logit model. If they are normally distributed, the probit model results. Since the two models generally give similar results in practice and the logit model is more easily estimated in multinomial extensions, we apply the logit model. Maddala (1983) presents a comprehensive presentation of these and related models, including estimation techniques and comparability of results.

The estimation method employs the logit model using grouped data where the underlying framework is discrete but the dependent variable is a proportion. Assuming the technology on each acre of land represents an observed technology choice, there are multiple observations for each farm with each choice having the same values for the independent variables. The on-farm observations can be grouped such that the dependent variable is the on-farm proportion of land under sprinkler irrigation systems. The proportion of land in sprinkler irrigation is an unbiased estimator of the probability of choosing sprinkler. The estimation method corrects for the heteroskedasticity induced by the farms having unequal number of observations.

A simpler version of the model focuses on the decision to use a particular technology or not. The model and estimation procedure is essentially the same, and has been applied to the adoption of tail-water pits using a sample of gravity irrigators.

In the logit model, the dependent variable is the log of the odds in favor of one alternative over the other, and the parameters may be interpreted as the partial derivatives of this logarithm with respect to the exogenous variables. The estimated coefficients can then be used, given a new farm with specified characteristics or a new set of characteristics for a sample farm, to predict the selection probabilities for each technology.

ESTIMATION

In this model, irrigation technology and tail-water pit choice depend on the price of water, the price of labor, expected climate, land topography, soil characteristics and farm size. The price of water is taken to be the energy cost of pumping the water to the surface with a 5 PSI head. The energy cost of water depends on the pumping lift, the price and type of fuel, and the energy efficiency of the pumping unit. We compute water cost using a set of engineering formulae, by fuel type, that assumes a standard fuel efficiency and system pressure (Gollehon, p. 54). State variation in fuel price and on-farm variation in pumping lift and fuel type produce substantial variation in water price across farms.

The selection equations include several proxy variables for evapotranspiration. Since expected weather in the growing season determines technology choice, the weather variables are historical averages for the length of the growing season, rainfall and the cumulative energy available to the plants. Because the actual climate may differ from the expected climate conditions, the observed technology choices are optimal, ex ante. The weather variables are: (1) the average number of frost-free days in the year, (2) the total precipitation for the growing season, May through September, and (3) the cumulative growing degree days, base 60, for the growing season, May through September. Growing degree days, base 60, are defined as the mean daily temperature minus 60 degrees if the mean exceeds 60 and zero otherwise.

Two soil texture dummy variables, two land capability classification dummies, and a land topography variable enter the technology choice equations as independent variables. All the soil characteristics are derived from the National Resource Inventory which contains county level data on soil texture, soil capability and land slope.

County observations of soil texture on cropland were classified on a five point scale where the numbers 1 through 5 indicate progressively clay-like textures (i.e., 1=sand, 2=sandy loam, 3=loam, 4=clay loam, 5=clay). The average for the county was then classified into three dummy variables representing sand, loam, and clay soils. Sand and clay dummies appear in the logit equations and measure the log of the odds relative to loam.

The land capability classification system groups soils based on their ability to produce common cultivated crops (USDA, SCS 1973). The land capability classes, identified numerically 1 through 8, indicate progressively greater limitations that restrict the use of the land for agriculture. Limitations include soils that are erosive, shallow, stony or wet. As with the soil texture variables, county observations of land capability on crop land were averaged and classified into dummy variables. The average of county observations on land capability is a continuous variable on the interval 1 to 8. Dummies for high productivity soils (land classification less than 2.5) and low productivity soils (land classification greater than 3.5) entered the equations accounting for the limitations of the soil for growing crops.

The topographical slope variable is the average slope on cropland in the county measured in percent slope.

Four regional dummies, South West, North West, Northern Plains and South, were included to capture location specific effects not already accounted for by climate and soil. All regional dummies reflect the log of the odds relative to the North East, the omitted dummy.

A variable for total on-farm irrigated acres was included to test for any scale effects. To the extent that scale effects are present, on-farm technology choices are not independent. Finally, the explanatory variables also include a dummy variable indicating the presence of surface water since conjunctive users may behave differently than users of exclusively groundwater.

DATA

Farm level data for acres of sprinkler and gravity irrigation, well pump fuel type, well depth, and the existence of tail-water pumps are from the 1984 Farm and Ranch Irrigation Survey (FRIS). The FRIS uses a sample of irrigators from the 1982 agricultural census stratified by state and farm size, designed to provide detailed data relating to on-farm irrigation practices. The <u>1984</u>

Farm and Ranch Irrigation Survey (1986), publishes aggregations of the survey data to the state level. The estimation procedure expands the sample to reflect the national population of groundwater irrigators.

Farm labor wages and energy prices by state for 1984 are from Agricultural Prices, 1984 Summary.

Climatological data from the National Climatic Data Center were merged with the farm level data by county. Variables for expected weather were derived from Climatography of the U.S. No. 20 (1986), a monthly summary of climatological observation from the NOAA cooperative network. County weather was obtained by matching the counties represented on the FRIS with the nearest cooperative weather station using state maps showing the location of the cooperative stations. Most stations were located within the county borders.

Soil texture, soil slope and land capability classification were obtained from the 1982 National Resource Inventory. For each county in the U.S. the National Resource Inventory sampled the physical characteristics of all non-federal rural land at several randomly selected points within the county. A total of nearly one million points were sampled in the United States. Land and soil characteristics within a county were quantified and averaged over only those county observations where crops were grown on the land. The land and soil characteristics were merged with the farm level data by county.

All acres in each county have been treated as identical because of the limitations of county-level soil, slope, and weather data. More disaggregated data, including information on capital investments in irrigation, would allow more detailed analysis. However, this unique set of farm-level irrigation data and county-level physical characteristics exhibits some important results.

RESULTS

Table 1 reports the maximum likelihood estimates of the irrigation technology and tail-water choice parameters and their elasticities. The log-likelihood tests, distributed Chi-square, for testing the models against an alternative in which all parameters are zero are also reported in Table 1 and both tests are rejected at the .001 level. The parameter estimates have the expected signs and are consistent with the theoretical predictions of Caswell and Zilberman (1986).

Sprinkler Technology Model

All coefficients except for two land capability and two regional variables were significantly different from zero at the 5% level. The price of water has the expected sign; the probability of adopting water saving technology increases with the cost of water.

Farm land with low water holding capacity due to porous soils or steep slopes, is unsuitable for gravity irrigation and, indeed, the results show that these farms are more likely to adopt sprinkler irrigation. Conversely, land that is level and high in clay content can achieve high application efficiencies with gravity systems. The results that show the presence of clay soils or level slopes promote the adoption of gravity irrigation. The hypothesis that soil productivity does not affect the choice of irrigation technology cannot be rejected at the 5% level.

Farms with access to surface water sources are more likely to choose a gravity system. Caswell and Zilberman (1985) suggest this result is not surprising since "surface water is supplied by water districts that, in most cases, have geared their water distribution system to the traditional technology" (p.229).

The coefficient on labor can be explained by the comparative labor intensity of the two irrigation systems. Gravity irrigation systems tend to be more labor intensive compared with sprinkler (Benson, Everson and Sharp). The negative coefficient indicates a shift to labor saving sprinkler irrigation in the presence of scarce labor.

The probability of adopting sprinkler relative to gravity technology varies positively with total rainfall and inversely with growing degree days and growing season length. Operators in regions with high rainfall are more likely to adopt sprinkler systems because sprinkler permits greater control over the quantity applied. In hot and windy regions, a significant amount of water applied through sprinkler systems evaporates, making sprinklers an inappropriate technology. The coefficient on growing degree days substantiates this effect. There are no strong a priori reasons to expect a negative coefficient on the length of the growing season. We offer two plausible explanations for the sign of the coefficient: First, short growing seasons correspond to colder climates where sprinklers are used for frost protection, and second, regions with long growing seasons tend to grow crops that are better suited to gravity systems such as cotton, orchards, and vegetables.

Calculating elasticities is useful for evaluating the relative contributions of explanatory variables to the probability of adopting sprinkler technology. Table 1 shows the estimated elasticities of the odds of adopting sprinkler, $\frac{\partial \log(P_S/P_G)}{\partial X_i} X_i = \beta_i X_i$, computed at the sample means. For example, the elasticity of the odds of the price of labor, estimated at the sample mean, is 1.63, indicating that a one percent rise in the price of labor would lead to a 1.63 percent increase in the odds of adopting sprinkler technology, P_S/P_G. The predicted change in the share of land under sprinkler irrigation depends on the initial share of land devoted to sprinkler. These elasticity estimates suggest the relative importance of variables other than the price of water. In particular, labor wages, topography, and, to a lesser extent, climate have the greatest impact on the selection probabilities.

Tail-water Pit Model

The results were similar to those obtained for sprinkler irrigation; high water prices increase the probability of adopting a water saving irrigation technology. The elasticity suggests that water price can be moderately effective in influencing the adoption of tail-water pits. However, climate and soil characteristics remain important determinants of the selection probabilities.

As expected, large farms, surface water sources, clay soils and moderate slopes increase the probability of adopting tail-water pits. Tail-water pits are effective only on soils with high water holding capacity.

The effects of labor wages and growing degree days are not statistically different from zero at the 5 percent level. Given the prior existence of a gravity system, tail-water pits do not require a significant amount of additional labor.

The probability of selecting a tail-water pit varies inversely with both the total rainfall and the length of the growing season. More rainfall reduces the effectiveness and the necessity of tail-water pits as the quantity of irrigation water applied falls and conservation is less essential.

Finally, long growing seasons have a significantly negative, and high productivity soils have a significantly positive impact on the selection probability. We offer two possible explanations: (1) productive soils warrant the application of additional water that can be supplied more cheaply by recirculating field run-off than withdrawing new water, and (2) regions with long growing seasons are highly correlated with surface water access and salinity control problems.

CONCLUSIONS

A wide range of factors influence irrigation technology choices. High water prices increase the likelihood of adopting a more efficient irrigation technology, but labor prices, soil texture, topography and climate may dominate technology choice decisions. The results suggest that water pricing policies aimed at converting land to more efficient irrigation technologies may be ineffective, if taken alone without regard to other determinants of technology choice.

The results do not imply that water demand is inelastic with respect to water prices. While technology choice may not be highly responsive to water prices, farm operators can adopt crop allocations that reduce water consumption. A more comprehensive model incorporating technology and land allocation choices in a simultaneous model, will shed more light on water demand and the determinants of technology choice.

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Table 1. Maximum Likelihood Estimates of Irrigation Technology and Tail-water Pit Discrete Choice Parameters.

	Sprinkler Irrigation			Tail-water pit		
Variable	Coef.	Standard error(a)	elast.	Coef.	Standard error(a)	elast.
Price of Water ($/acre-foot)	.011	.00316**	.21	.0293	.00443**	.59
Price of Labor ($/hour)	.379	.101**	1.63	.280	.188	1.21
Irrigated Acres (100 acres)	-.0021	.00052**	-.044	.002	.000714**	.058
Surface Water	-0.78	.0865**		.423	.114**	
<u>Climate Variables</u>						
Frost free days (number/year)	-.0039	.00165**	-.97	-.008	.00261**	-1.91
Total rainfall (inches May-Sept)	.023	.00815**	.30	-.035	.0117**	-.41
Growing deg. days (100 gdd May-Sept)	-.031	.0116**	-.56	.002	.0164	.038
<u>Soil Variables</u>						
Soil slope (percent slope)	.33	.0288**	.67	-.103	.0445**	.71
High Productivity	-.151	.0842*		.401	.112**	
Low Productivity	-.026	.114		-.763	.228**	
Sand	1.27	.105**		-.237	.175	
Clay	-.64	.124**		.608	.144**	
<u>Region</u>						
North West	-.16	.220		-2.10	.498**	
South West	-1.35	.240**		-.375	.528	
South	-0.35	.271		-1.76	.883**	
Northern Plains	-1.38	.219**		.466	.520	
No. Observations	4832			1845		
Log-Likelihood	-2620			-1915		
Log-L (slope=0)	-3280			-2395		
Chi-Sq (15 d.f.)	1318			960		
Sig. Level	.32 x 10(-13)			.32 x 10(-13)		

(a) asymptotic standard error

** Significant at the .05 level

* Significant at the .10 level

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