The Effect of Land Allocation, Soil Quality, and Water Cost on Irrigation Technology Choice

by

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Presented at the American Agricultural Economic Association Meetings
Indianapolis, Indiana
August 1995

The authors would like to thank Cliff Trotter, Steve Collup, Hodge Black, and Helen Kim for their assistance with this study. This research was supported by a Challenge Grant from the United States Bureau of Reclamation. Any opinions, findings conclusions or recommendations expressed here are those of the authors and do not necessarily reflect the views of the Bureau or the Arvin Edison Water Storage District. Any omissions or errors are the responsibility of the authors.

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The continued growth of urban water demand, the recent awareness of environmental and in-stream water values, and the virtual halt of water supply development has put increased demands on California's limited water supply. Recent legislation has called for increased in-stream water flows to enhance water quality and wildlife habitat in California. Because agricultural water use accounts for eighty percent of California's water consumption, and in many regions has the capability to dramatically increase water use efficiency, the burden to meet the growing demands is coming at the expense of agriculture. Adoption of modern irrigation technologies is often cited as a key to increasing water use efficiency in agriculture.

The literature on modern irrigation technology adoption is well established both empirically (Caswell and Zilberman [1985], Negri and Brooks, and Dinar and Yaron [1990]) and theoretically (Caswell and Zilberman [1986]). However, most empirical studies have been criticized because they are based on data of regional averages and compare degrees of adoption at the state or county level. Using aggregate data may bias the results by modeling the growers as having more choices than they actually do, which will not accurately capture grower response to policy changes. We will use field level data that will allow a one to one matching of the technology adopted and field characteristics, while previous studies were only able to use proportions.

Most studies have focused on technology adoption for a specific crop or sub-group of crops. Using data with diverse land allocation among annual and perennial crops from the same region will allow a direct comparison of the effect of crop type on technology adoption. In addition, the literature has found that soil quality and water cost

To estimate the model parameters it is necessary to choose a distribution for the ε_{ij}'s, and thus the distribution of the difference of the error terms. Two common assumptions are either the normal or the Weibull distributions (Domencich and McFadden). Normal random variables have the property that any linear combination of normal variates is normal. The difference between two Weibull random variables has a logistic distribution, which is similar to the normal but with larger tails. Thus, the choice is somewhat arbitrary, especially with large sample sizes. We will assume that the ε_{ij}'s follow a Weibull distribution. Given this assumption, the probability that the *i*th technology is adopted on the *j*th field is given by

(3) $$P_{ij} = \frac{e^{\beta_i' X_j}}{\sum_i e^{\beta_i' X_j}}, \; i = 0, I \; and \; j = 1, J.$$

These give the estimation equations for the standard multinomial model that is based on the characteristics of the field, not the characteristics of the choice. In this model the individual characteristics do not vary across choices. The question that this model answers is; given a new field with specified characteristics, we can predict the probability that one of the *i* technologies considered will be chosen on that field.

The effect of each of these variables is captured in the estimated parameters, β_i. The difference in characteristics across fields will effect the technology choice via the perceived yield and cost effects on the profitability of the technology on a specific field. This differs from previous studies that have looked at how regional differences affect the profitability. While the previous results have given insight to regional differences, they do not correspond to individual grower choices given the field characteristics they face.

order to match the data to each quarter section it was necessary to take weighted averages of the soils within each quarter section. To match the quarter sections, which are 160 acre plots, to the specific fields the District land maps were used to find which quarter section each field was in. Soil permeability and field slope were given in inches per hour and percent, respectively. Both soil permeability and slope were given in ranges, for each the midpoint was taken and used to construct weighted averages for each quarter section. All data from the District is for the 1993 growing year and is a cross-section of all growers in the District.

The model is applied to explain the use of the different types of irrigation technologies as a function of the characteristics of the fields they are used on. The estimation equations in (3) provide a set of probabilities for the $I + 1$ choices faced by the decision maker. To proceed we must remove an indeterminacy in the model. A convenient normalization that solves this problem is to assume that $\beta_0 = 0$. We can then take the log and estimate the log odds ratio of choosing the ith technology over the traditional technology on the jth field. This is given by

$$(4) \qquad \ln \frac{P_{ij}}{P_{0j}} = \beta_i' X_j, \quad i = 1, 2 \text{ and } j = 1, 2, \dots 1493.$$

The coefficients can be interpreted as the marginal impact of the variable on the log odds of selecting a modern technology relative to the traditional technology.

There were 1493 field observations covering 94,000 acres and eight variables; four continuous, (a) field size, (b) field slope, *(c)* soil permeability, and *(d)* cost of water; and four binary *(e)* water source, *(f)* citrus crop, *(g)* deciduous crop, and *(h)* grape vineyard. Truck crops were used as a benchmark for all crops because they had the best

Table 1: Estimation Results, Elasticities, and Probabilities

Variable	Estimation Results[b]		Elasticities[a]		
	Sprinkler	Drip	Furrow	Sprinkler	Drip
Constant	1.9855 (3.372)	-4.5480 (-7.701)			
Water cost ($/acre-foot)	-0.0130 (-1.333)	0.0257 (3.151)	-0.24	-0.84	0.96
Surface water (1/0)	-0.5099 (-1.636)	0.9706 (3.930)	[-0.11]	[-0.12]	[0.23]
Soil permeability (in./hr.)	0.0002 (0.005)	0.0529 (2.082)	-0.04	-0.04	0.11
Field slope (%)	0.2210 (1.846)	0.6277 (8.081)	-0.32	0.01	0.61
Field size (acres)	0.0101 (4.714)	0.0065 (4.028)	-0.19	0.34	0.15
Crops					
Citrus (0/1)	-5.1537 (-8.380)	2.1117 (6.095)	[-0.21]	[-0.37]	[0.58]
Deciduous (0/1)	-2.3600 (-11.186)	1.3872 (4.064)	[-0.16]	[-0.23]	[0.39]
Grapes (0/1)	-6.3777 (-12.061)	0.6760 (2.052)	[0.24]	[-0.57]	[0.33]
Probability of adoption evaluated at variable means			.54	0.18	0.28
Observations	1493				
McFadden R^2	.44				
Likelihood ratio test: χ^2_{16}	1441.16				
Correct prediction	74%				

[a]Terms in brackets are not elasticities, they are the change in the probability of adoption as the discrete variable changes from 0 to 1.
[b]Terms in parenthesis are asymptotic t-statistics.

to the physical characteristics of perennial crops. High-pressure sprinklers disperse water over a large area saturating the crop with water, which will cause decay in many perennial crops, as well as some annual crops. Under drip irrigation the results are less pronounced yet still evident. This corresponds with the knowledge that many perennial crops can still be competitively grown with the traditional technology under the right growing conditions. The influence of crop type on technology choice is best seen in the change in probability figures. These show that if perennial crops are grown there is a

Sprinkler irrigation has been employed in the District since the early 1960s and is widely utilized on crops that grow well with this technology. In particular, Table 1 shows that truck crops and cotton are grown largely under sprinkler irrigation. Significantly, potato growers in the District, who have employed sprinklers since the 1960s are now beginning to convert to low-pressure systems (especially drip tape) in response to changes in water price. This observation is consistent with the findings of Dinar and Yaron (1992) who estimated technology cycles for Israeli citrus crops. In their model of technology adoption and abandonment, Dinar and Yaron (1992) estimate the technology cycle of hand-move sprinkler irrigation to range from 22 to 24 years[1].

The coefficients for the land quality variables, soil permeability and field slope, are of the expected sign and magnitude. We show that sprinklers are not as sensitive to land quality as drip irrigation, which corresponds with the level of diffusion of sprinklers. Sprinkler irrigation is a standard of production for annual crops in the District, and in most cases growers are not competitive without it. However, drip irrigation is highly dependent on land quality characteristics, especially field slope. Prior to the use of drip irrigation it was not possible to grow irrigated crops on lands with steep slope. The introduction of drip allowed cultivation of land that had previously been unproductive. This is best seen in Figures 2 and 3. Here we see that variation in soil permeability and slope have a dramatic effect on furrow and drip irrigation. This indicates that a field that is relatively flat with non-permeable soils is likely to continue using traditional technologies rather than adopt drip.

Caswell and Zilberman (1986) showed theoretically that modern irrigation technologies are less likely to be adopted on fields with surface water supplies rather than groundwater supplies. In this case we see that this holds for sprinkler irrigation, but not

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[1]This not only suggests that the probability of adoption depends on where it is on its diffusion curve, but more importantly that the grower response to a pricing policy may also depend on where on the diffusion curve a given technology is.

opposite should be true, and adoption of sprinklers should be more sensitive to water price than abandonment.

Our results indicate that to accurately predict grower response to agricultural water policy it is necessary to account for land allocation, soil quality, and the cost of water. While the cost of water is an important policy tool and determinant of water use, it is not the only, or even the most important, factor for affecting the adoption of modern irrigation technology. Land allocation and soil quality condition on the growers choice of technology, and therefore, introduce rigidities to adoption. This implies that agricultural water policy must allow the grower flexibility in their response. Water policy that imposes large fixed costs, best management practices, or land allocation restrictions will most likely result in inefficient changes in water use.

Our results for the adoption of drip irrigation with respect to the cost of water and soil quality generally confirm those of aggregate studies. However, they differ significantly for sprinkler irrigation. This shows that for certain irrigation technologies and regions the aggregate studies are not accurate. This may vary across technologies and regions depending on regional characteristics of technology diffusion, soil quality, range and level of water cost, and crops grown. This indicates that policy analysis must be specific to a given region in order to accurately predict grower response and design of policy.

Figure 1: Probability of Adoption by Marginal Water Price

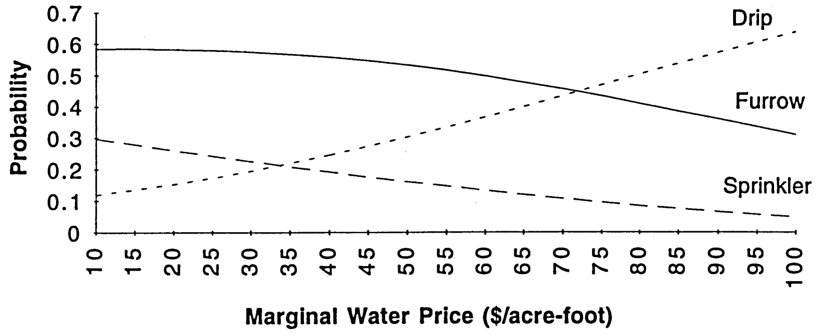

Figure 2: Probabiility of Adoption by Soil Permeability

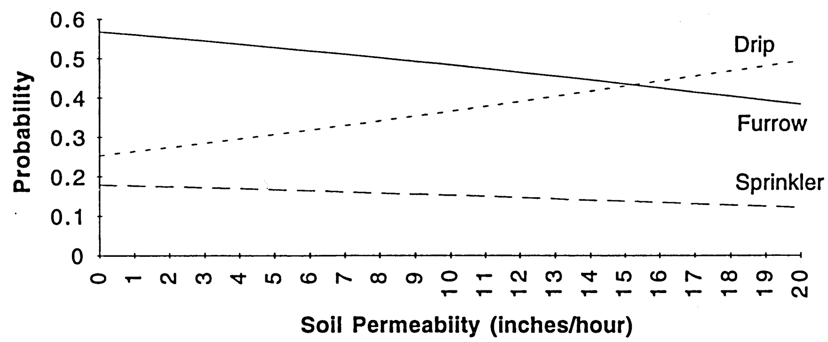

Figure 3: Probability of Adoption by Field Slope