Appendix 5

Explaining Irrigation Technology Choices: A Microparameter Approach

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Water price reforms are increasingly being used to encourage improvements in irrigation efficiency through technology adoption. A microparameter approach based on field-level data is used to assess the effect of economic variables, environmental characteristics, and institutional variables on irrigation technology choices. The results show that water price is not the most important factor governing irrigation technology adoption; physical and agronomic characteristics appear to matter more. The results demonstrate the importance of using micro-level data to determine the effects of asset heterogeneity and crop type on technology adoption.

Key words: asset heterogeneity, irrigation technology, microparameters, water policy.

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 have put increased demands on scarce water supplies in the western United States. Recent legislation has called for increased in-stream water flows to enhance water quality and restore wildlife habitat in a number of states, especially California. Because agricultural water use accounts for the majority of water consumption in the West, growers are generally forced to bear the burden of reduced diversions necessary to enhance in-stream flows and meet increasing urban demand.

Adoption of modern irrigation technologies is often cited as a key to increasing water use efficiency in agriculture and reducing the use of scarce inputs (Cason and Uhlaner) while maintaining current levels of production. Policy makers have tried to encourage adoption of modern technologies in several ways. For example, the California legislature recently enacted a measure (A.B. 3616) requiring irrigation districts in the state to draft "best management practices" for the use of irrigation water, including farm-level measures such as irrigation systems. Water price reforms are also increasingly used to encourage improvements in irrigation efficiency through technology adoption. The federal Central Valley Project Improvement Act requires the U.S. Bureau of Reclamation to adopt increasing block pricing for water provided to irrigation districts.

The literature on adoption of modern irrigation technology is well established both empirically (see especially Caswell and Zilberman 1985, Lichtenberg, and Negri and Brooks) and theoretically (Caswell and Zilberman 1986, Dinar and Zilberman). Theoretical research has identified three broad classes of factors affecting irrigation technology choice: economic variables, environmental characteristics, and institutional variables. These exogenous factors all vary at the level of the individual decision maker, and are thus commonly called microparameters (following Hochman and Zilberman).

Despite the importance placed on micro-level variations in the theoretical literature, most empirical studies of irrigation technology adoption suffer from the use of regional average data on technology choices, and resort to comparing percentages of adoption among states or counties. Previous empirical studies have not been able to match technology choice on a one-to-one basis with micro-level variables, such as water-holding capacity, field gradient and size,

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low a Weibull distribution. Given this assumption, the probability that the ith technology is adopted on the jth field is

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

These give the estimation equations for the standard multinomial logit model that is based on the characteristics of the field, not the characteristics of the choice. In this model the parameters vary across technology choices, but not across field characteristics. Thus, the number of estimated parameters is equal to the number of characteristics times the number of choices.

The effect of each of these variables is captured in the estimated parameter vector β. The difference in characteristics across fields affects the technology choice via the perceived effect on the profitability of production on a specific field. This differs from previous studies that have looked at how regional differences affect 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.

Data and the Empirical Model

The model is applied to the Arvin Edison Water Storage District (the District) located in the southern San Joaquin Valley in central California. Because of the regional climate and favorable soils, growers in the District benefit from an early harvest season that allows for diverse cropping patterns, as shown in table 1. In addition, there has been a large degree of irrigation technology adoption—30% furrow or flood, 37% high-pressure sprinkler, and 33% low-pressure drip and micro-sprinkler (table 1). The distribution of crops and irrigation technologies makes the District ideal for analysis; yet, the area is relatively small, so the growers participate in many of the same markets and institutions.

The data on crop choice, irrigation technology, price of water, and water source were collected by the District. The study considers four crop categories: truck crops, citrus trees, deciduous trees, and grape vineyards. Taken together, these crops constitute 76% of the cultivated acreage in the District. The remaining acreage is distributed among grains, irrigated pasture, cotton and dry land crops.

Table 1. Irrigation Technology and Acreage by Crop

		Percentage of Acreage by Irrigation Technology		
Crop	Acreage	Furrow	Sprinkler	Drip
Citrus	12,065	15%	1%	84%
Deciduous	11,700	27%	33%	40%
Grapes	23,665	61%	2%	37%
Truck Crops	27,283	11%	86%	3%
Total	74,713	30%	37%	33%

Irrigation technologies are consolidated into three groups based on the required level of pressurization. These are as follows: (*i*) furrow, flood, and border, which are considered the traditional or gravity technology, and are used on all types of crops; (*ii*) high-pressure sprinklers, which are used primarily on truck and deciduous crops; and (*iii*) low-pressure systems like drip, micro-sprinklers, and fan jets, which are also used in each crop group.

There are several important points to be raised concerning low-pressure technologies and perennial crops in the District. First, low-pressure systems such as drip only wet a small area of soil. As a result, perennial crops under drip irrigation form a smaller root system than if a traditional irrigation system were used. Many growers feel that this makes the crop more susceptible to disease and the accumulation of salts, which reduces the attractiveness of these systems. Second, many of the perennial crops were established prior to the introduction of low-pressure systems. Because different types of root systems are developed under the different types of technologies, growers are reluctant to switch technologies on an established crop for fear of damaging the crop. To combat these potential problems, growers have used multiple emitters for each tree to achieve a larger area of water dispersion.

The marginal price of groundwater is estimated by the District based on depth to groundwater and the energy cost for the size of pump needed to lift water from a given depth. The marginal price for surface water is the variable component of the District charge for each acre-foot that is actually delivered. In 1993, marginal water price ranged from $12 to $57 per acre-foot for surface water and $40 to $88 per acre-foot for groundwater. Though the marginal price of groundwater is about $25 more per acre-foot than surface water, the fixed compo-

Table 2. Estimation Results, Elasticities, and Probabilities

	Estimation Results[a]		Elasticities[b]		
Variable	Sprinkler	Drip	Furrow	Sprinkler	Drip
Constant	1.9855	–4.5480			
	(3.372)	(–7.701)			
Water price ($/acre-foot)	–0.0130	0.0257	–0.24	–0.84	0.96
	(–1.333)	(3.151)			
Surface water (0/1)	–0.5099	0.9706	[–0.11]	[–0.12]	[0.23]
	(–1.636)	(3.930)			
Soil permeability (in/hr)	0.0002	0.0529	–0.04	–0.04	0.11
	(0.005)	(2.082)			
Field slope (%)	0.2210	0.6277	–0.32	0.01	0.61
	(1.846)	(8.081)			
Field size (acres)	0.0101	0.0065	–0.19	0.34	0.15
	(4.714)	(4.028)			
Crops					
Citrus (0/1)	–5.1537	2.1117	[–0.21]	[–0.37]	[0.58]
	(–8.380)	(6.095)			
Deciduous (0/1)	–2.3600	1.3872	[–0.16]	[–0.23]	[0.39]
	(–11.186)	(4.064)			
Grapes (0/1)	–6.3777	0.6760	[0.24]	[–0.57]	[0.33]
	(–12.061)	(2.052)			
Probability of adoption evaluated at variable means			0.54	0.18	0.28
Observations	1,493				
McFadden R^2	0.44				
Likelihood ratio test: χ^2_{16}	1,441.16				
Correct prediction	74%				

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

crop type on technology choice is also reflected in the change in probability figures in table 2. These results show that a grower producing perennial crops is much more likely to adopt drip than furrow or sprinkler irrigation. For example, growing citrus trees increases the probability of adopting drip by 58%, holding all other variables at their mean value. Previous studies that focused on a small number of crops (Lichtenberg, Shrestha and Gopalakrishnan) could not fully identify the importance of crop type on irrigation technology adoption.

Economic factors are also important in determining irrigation technology choices. The coefficient on the water price variable in the drip equation is positive and significant, confirming previous findings that water-saving technology will be adopted as water price increases. However, the coefficient on water price in the sprinkler equation is negative. Figure 2 shows the change in the probability of adoption as a function of the price of water, with all other variables set at their mean values. This figure demonstrates that, as the price of water increases, growers switch from both furrow and sprinkler irrigation technologies to drip.

The results in table 2 and figure 2 are in sharp contrast to the results of previous studies that have found similar adoption patterns for high- and low-pressure irrigation systems. For example, Caswell and Zilberman (1985) report coefficients of 0.03 on marginal water price in equations explaining both drip and sprinkler adoption, and Cason and Uhlaner estimated water price coefficients between 0.02 and 0.07 for all technologies, depending on the region. The results differ from these studies for several reasons. Examining several technology choices simultaneously gives a more complete picture of grower decision-making behavior and allows for explicit estimation of marginal probabilities. Further, growers in this study farm in an arid, hot climate and pay more for water than irrigators in many other areas. As a result, the diffusion process for pressurized technologies is more advanced in the District than in other

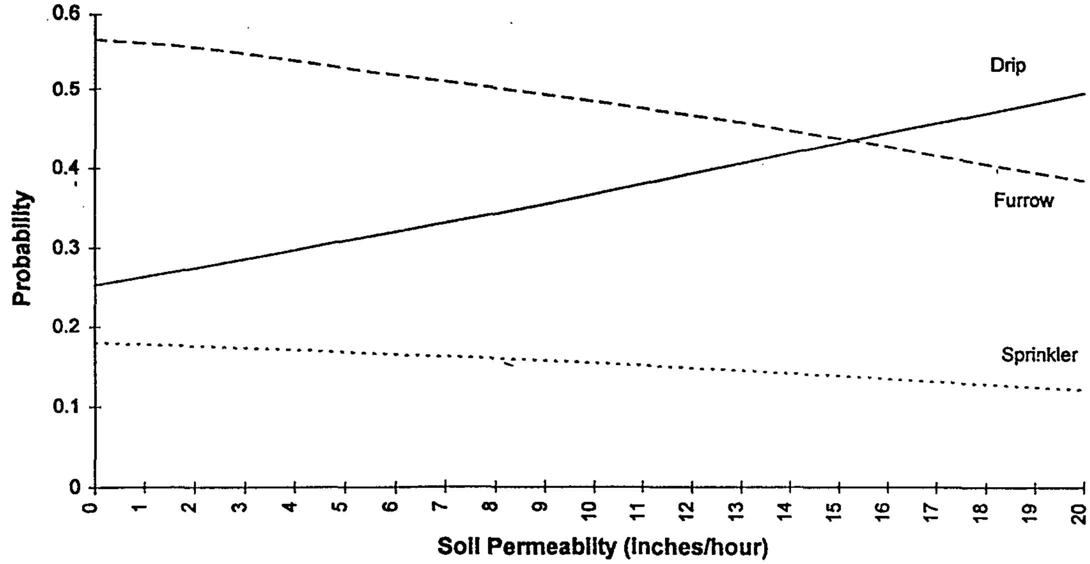

Figure 3. Probability of adoption by soil permeability

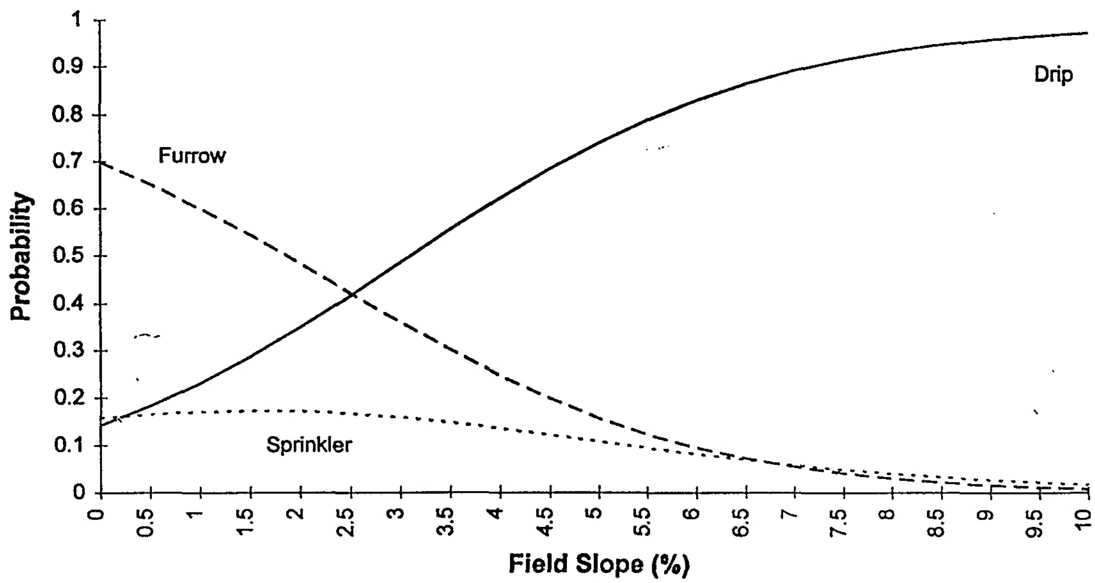

Figure 4. Probability of adoption by field slope

tive to land quality as drip irrigation, which is especially dependent on field slope. Prior to the introduction of drip irrigation, it was difficult and costly to grow irrigated crops on lands with steep slopes. As a result, the introduction of drip has allowed cultivation of land that had previously been unproductive. This relationship is best seen in figures 3 and 4, which show that variations in soil permeability and slope have a dramatic effect on the probability of adopting furrow and drip irrigation.

Caswell and Zilberman (1986) show theoretically that modern irrigation technologies are less likely to be adopted on fields with surface water supplies rather than groundwater supplies on the assumption that surface water is supplied at lower pressure than groundwater. The statistical results show that sprinkler adoption is less

References

Amemiya, T. "Qualitative Response Models: A Survey." *J. Econ. Lit.* 19(December 1981):1483–1536.

Bellon, M.R., and J.E. Taylor. "'Folk' Soil Taxonomy and the Partial Adoption of New Seed Varieties." *Econ. Develop. and Cultur. Change* 41(July 1993):763–86.

Cason, T.N., and R.T. Uhlaner. "Agricultural Production's Impact on Water and Energy Demand: A Choice Modeling Approach." *Resour. and Energy* 13(December 1991):307–21.

Caswell, M.F., and D. Zilberman. "The Choices of Irrigation Technologies in California." *Amer. J. Agr. Econ.* 67(May 1985):223–34.

———. "The Effects of Well Depth and Land Quality on the Choice of Irrigation Technology." *Amer. J. Agr. Econ.* 68(November 1986):798–811.

Davies, S. *The Diffusion of Innovations.* Cambridge: Cambridge University Press, 1979.

Dinar, A., and D. Yaron. "Adoption and Abandonment of Irrigation Technologies." *Agr. Econ.* 6(April 1992):315–32.

Dinar, A., and D. Zilberman. "The Economics of Resource-Conservation, Pollution-Reduction Technology Selection: The Case of Irrigation Water." *Resour. and Energy* 13(December 1991):323–48.

Domencich, T., and D. McFadden. *Urban Travel Demand: Behavioral Analysis.* Amsterdam: North-Holland Publishing, 1975.

Hochman, E., and D. Zilberman. "Examination of Environmental Policies Using Production and Pollution Microparameter Distributions." *Econometrica* 46(July 1978):739–60.

Lichtenberg, E. "Land Quality, Irrigation Development, and Cropping Patterns in the Northern High Plains." *Amer. J. Agr. Econ.* 71(February 1989):187–94.

Negri, D., and D. Brooks. "Determinants of Irrigation Technology Choice." *W. J. Agr. Econ.* 15(December 1990):213–23.

Perrin, R.K., and D. Winkelmann. "Impediments to Technical Progress on Small versus Large Farms." *Amer. J. Agr. Econ.* 58(December 1976):888–94.

Shrestha, R., and C. Gopalakrishnan. "Adoption and Diffusion of Drip Irrigation Technology: An Econometric Analysis." *Econ. Develop. and Cultur. Change* 41(January 1993):407–18.

Stoneman, P.L., and N. Ireland. "Technological Diffusion, Expectations and Welfare." *Oxford Econ. Pap.* 38(July 1986):283–304.