# Explaining Irrigation Technology Choices: A Microparameter Approach

Gareth Green, David Sunding, David Zilberman, and Doug Parker

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,

Gareth Green is assistant professor of agricultural economics at Washington State University; David Sunding is a senior economist with the Council of Economic Advisers, Executive Office of the President; David Zilberman is professor and Doug Parker is extension specialist, both in the Department of Agricultural and Resource Economics at the University of California, Berkeley.

This research was supported by a Challenge Grant from the United States Bureau of Reclamation in cooperation with the National Heritage Institute. 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. The authors would like to thank Cliff Trotter, Steve Collup, Helen Kim, and two anonymous reviewers. Any omissions or errors are the responsibility of the authors.


Copyright 1996 American Agricultural Economics Association

C—097388

C-097388

water price, and water supply source. Averaging data on a regional basis has a homogenizing influence on both grower behavior and physical characteristics; it may obscure the effect of micro-variables, and, as a result, it may seriously bias statistical estimates of adoption behavior.

In this study, a microparameter approach based on field-level data is used to assess irrigation technology choices. This study has several advantages over previous empirical analyses of irrigation technology adoption: (*i*) a multinomial model is used rather than a binomial model so it is possible to examine switching between modern technologies, in addition to switching from traditional to modern technologies; (*ii*) the empirical model includes a complete set of physical characteristics observed at the field-level, thereby avoiding misspecification problems inherent in earlier models based on grouped data; (*iii*) all members of the data set face the same institutions and input and output markets, so it is not necessary to use regional dummy variables that obscure important statistical relationships; (*iv*) both annual and perennial crops are included, whereas previous studies only included one or the other; and (*v*) the soil data variables are continuous rather than ranked, as is the case in most other studies. As a result of the disaggregated microparameter approach, we obtain more accurate conclusions regarding the effect of soil characteristics and water price on irrigation technology adoption, and overthrow or significantly modify some of the conventional wisdom regarding irrigation technology adoption.

We first present a theoretical discrete choice model and show how it relates to the grower's decision problem. Then cross-section data from a central California irrigation water district are employed to estimate an empirical model. This is followed by a discussion of the results, paying special attention to variables that are the most influential to irrigation technology choice.

## Model of the Adoption Decision

The grower decides which irrigation technology to adopt on the *j*th field by estimating expected profits under each of the *i* technologies, while taking into account what type of crop is grown and the field's characteristics. The grower chooses the technology that maximizes perceived profits, given that crop choice already has been made.[1] In this study crop and technology choice is modeled as sequential. An alternative assumption would be to model the crop and technology choice simultaneously, as suggested by Negri and Brooks and by Lichtenberg. While this may be appropriate for grain crops, it does not appear to be appropriate for high-value fruits and vegetables. The distinction is that the production of high-value crops involves extremely specialized capital, where grains are not as highly specialized. Therefore, even though the actual investment in a new crop and technology physically may be made at the same time, the decision to invest is made sequentially. To test this, a model of simultaneous crop and technology choice was estimated. The model had inconsistent results, predicted poorly, and was statistically insignificant.

Given the assumption of sequential choice, the per acre profits are given by

$$(1) \qquad \pi_{ij} = \beta_i' X_j + \varepsilon_{ij}$$

where $\beta_i$ is a vector of estimable parameters, $X_j$ is a vector of observed field characteristics (including crop choice), and $\varepsilon_{ij}$ is an unobserved scalar associated with unmeasured characteristics. Setting the index of the traditional technology to $i = 0$, the grower selects the *i*th modern technology if

$$(2) \qquad \beta_i' X_j - \beta_0' X_j > \varepsilon_{0j} - \varepsilon_{ij}.$$

To estimate the model parameters, it is necessary to choose a distribution for the $\varepsilon_{ij}$'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 assume that the $\varepsilon_{ij}$'s fol-

[1] Though much of the more general literature on technology adoption examines profit risk, this is not of great concern in the irrigation technology adoption literature. Note that pressurized irrigation technologies generally increase uniformity of input application, decrease output variability, and increase expected yields. The net result of these attributes to risk considerations is ambiguous since they affect risk in opposite directions.

low a Weibull distribution. Given this assumption, the probability that the $i$th technology is adopted on the $j$th 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-

C—097390

C-097390

nent of the District charge for surface water is set so that the total price for ground and surface water is approximately the same, ranging from $50 to $110 per acre-foot.

The Kern County Natural Resource Conservation Service collected data on soil permeability and field slope to define land quality for each quarter section. To match the quarter sections (which are 160-acre plots) to the specific fields, District land maps were used to identify the exact location of each field. Permeability and slope were given in inches per hour and percentage, respectively. Figure 1 shows the distribution of irrigation technology for given slope ranges. Note that when the slope increases so does the percentage of acreage under drip irrigation. This indicates that the grower's irrigation technology choice is conditioned on land characteristics. The effect of soil permeability on technology choice is not as distinct.

The econometric model explains the use of the different types of irrigation technologies as a function of the characteristics of the fields for which they are used. The estimation equations in (3) provide a set of probabilities for the $I + 1$ choices faced by the decision maker. However, to proceed it is necessary to remove an indeterminacy in the model. A convenient normalization is to assume that $\beta_0$ is a vector of zeros. We can then take the log and estimate the log odds ratio of choosing the *i*th technology on the *j*th field. This is given by

$$(4)\ \ln \frac{P_{ij}}{P_{0j}} = \beta_i' X_j,\ i = 1, 2, \text{ and } j = 1, 2, \ldots, 1{,}493.$$

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

The data for the study are from the 1993 growing year and there are 1,493 fields cultivated by approximately 350 growers. Though we are unable to identify which growers cultivated which fields, based on sample interviews we determined that most growers had fewer than four fields and grew at least two different crops. Growers that had a large number of fields grew at least five crops. There are eight independent variables: four continuous—(*a*) field size, (*b*) field slope, (*c*) soil permeability, and (*d*) price of water; and four binary—(*e*) water source (i.e., groundwater or both ground and surface water), (*f*) citrus crop, (*g*) deciduous crop, and (*h*) grape vineyard. Without loss of generality, truck crops and gravitational technology are used as benchmarks for crops and technology choice.

## Results

The Limdep statistical package is used to estimate the parameters of the model using maximum likelihood estimation and Newton's method. We report the coefficients, asymptotic t-statistics, and three statistical tests to evaluate the performance of the model. To allow comparison of adoption rates among traditional, sprinkler, and drip technologies, we calculate the probability of adoption, the elasticity of the continuous variables, and the percent change in probability of the discrete variables if they were to change from 0 to 1. These are all reported in table 2.

Of the coefficient estimates in table 2, more than half are significant at the 0.0001 level, and all but two were significant at the 0.07 level. To measure the performance of the model, the McFadden $R^2$, the log-likelihood ratio test, and the percentage of correct predictions are reported. The McFadden $R^2$ is calculated as $R^2 = 1 - L_\Omega/L_\omega$, where $L_\Omega$ is the unrestricted maximum log-likelihood and $L_\omega$ is the restricted maximum log likelihood with all slope coefficients set equal to zero (Amemiya). The log-likelihood ratio test is given by $2(L_\Omega - L_\omega)$ and is asymptotically distributed as a chi-squared random variable. The percentage of correct predictions is calculated as the total number of correct predictions as a percentage of the number of observations. Each of these measures indicate that the model has strong explanatory power.

The statistical results indicate that the adoption of irrigation technologies is highly dependent on crop choice. The coefficients on the perennial crop variables in the sprinkler technology equation are all negative, large, and highly significant. This result implies that the probability of adopting sprinkler rather than the traditional technology is low for perennials, and reflects the physical characteristics of perennial crops. For example, high-pressure sprinklers disperse water over a large area saturating the tree and causing fruit decay, which is not a problem for many annual crops such as potatoes. Crop choice also strongly affects drip adoption, although in nearly the opposite way as for sprinklers. Perennial crops, especially citrus trees, are more likely to be grown under drip irrigation than annuals. The influence of

C—097391

C-097391

Table 2. Estimation Results, Elasticities, and Probabilities

| Variable | Estimation Results[a] Sprinkler | Estimation Results[a] Drip | Elasticities[b] Furrow | Elasticities[b] Sprinkler | Elasticities[b] 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: $\chi^2_{16}$ | 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

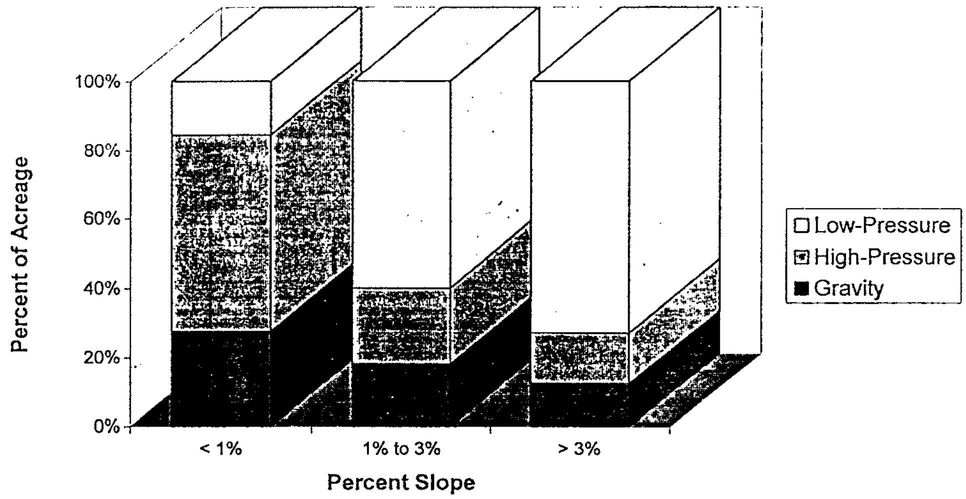


**Figure 1. Irrigation technology by slope**

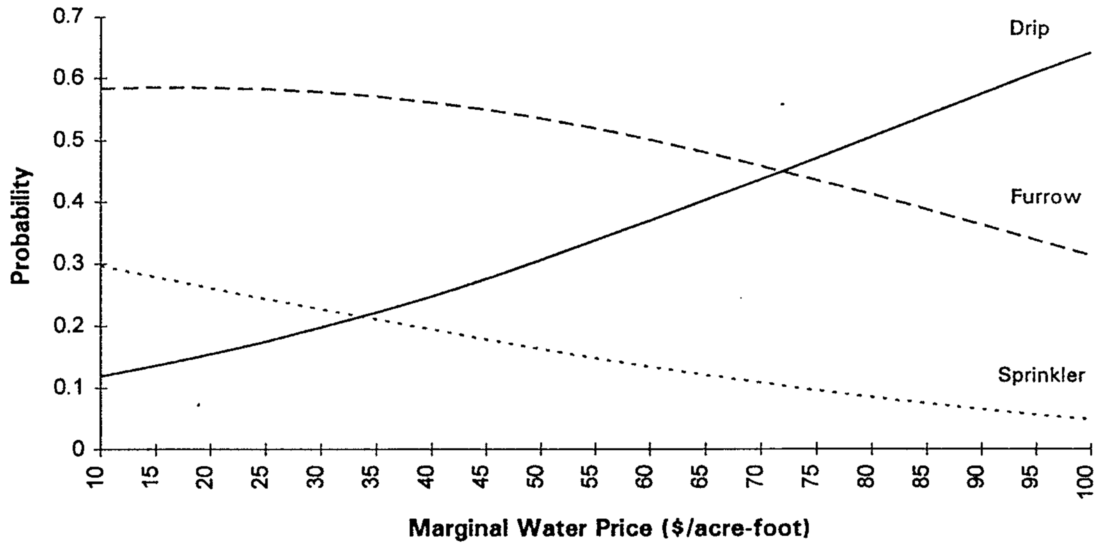


**Figure 2. Probability of adoption by marginal water price**

regions, and sprinkler technologies appear to be nearing the end of their product life cycle. 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 are grown largely under sprinkler irrigation. However, potato growers in the District 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. In their model of technology adoption and abandonment, Dinar and Yaron estimate the technology cycle of hand-move sprinklers to range from twenty-two to twenty-four years.

The coefficients on the land quality variables—soil permeability and field slope—are of the expected sign and magnitude. Again, however, there are important differences between technologies in terms of the effect of land quality variables. Sprinkler adoption is not as sensi-

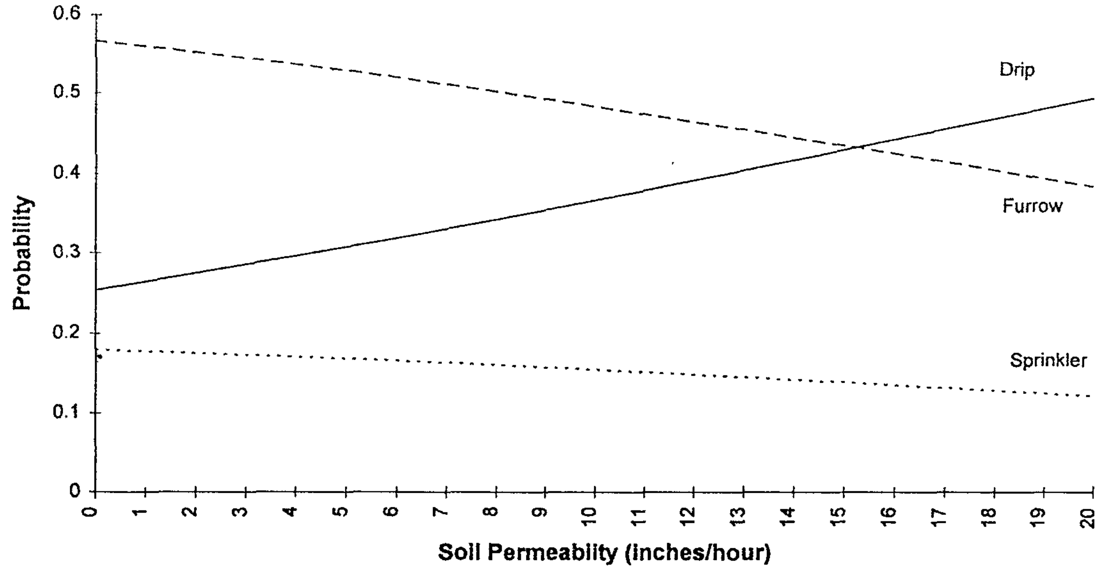


**Figure 3. Probability of adoption by soil permeability**

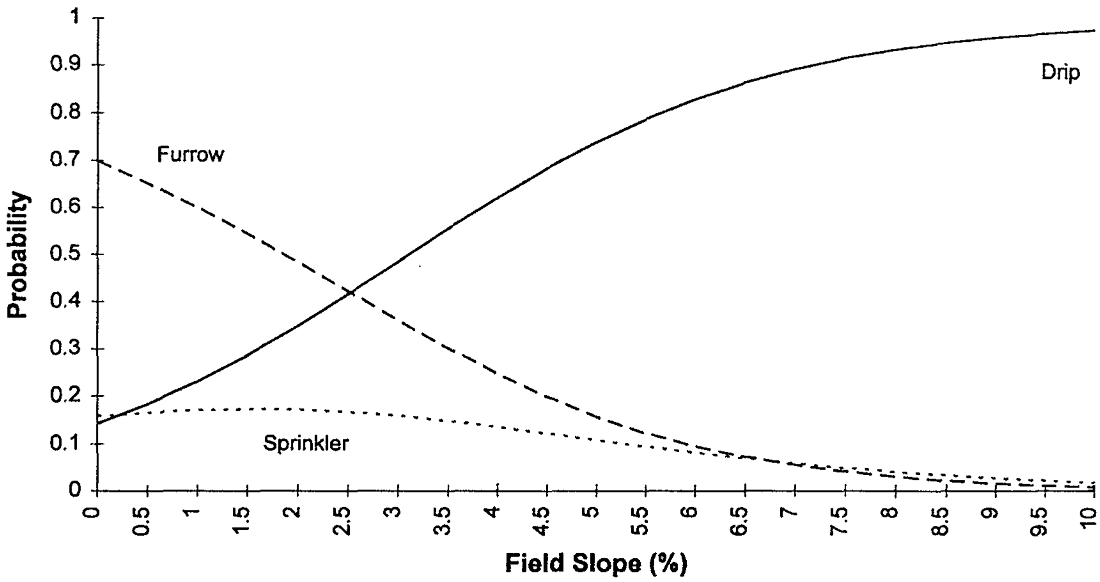


**Figure 4. Probability of adoption by field slope**

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 likely to be adopted in areas with surface water supplies, but that drip adoption is more likely with surface supplies. While the District is one of the few California districts supplying pressurized surface water to its growers, the pressure is not consistent and is only sufficient to run a low-pressure system such as drip.

## Policy Implications

The results of this study point out that cross-section technology adoption coefficients must be interpreted with the dynamic diffusion process in mind and also show that the effect of economic factors such as price on adoption is path-dependent. For example, in the results, we obtained a negative coefficient on the water price variable for adoption of sprinkler irrigation, which would seem to refute the theoretical and empirical literature. However, high-pressure sprinklers are widely adopted in the study area, and because these technologies are far from the beginning of their life-cycle in the District, abandonment of sprinkler technologies is more sensitive to water price increases than adoption. In another area where growers rely more on gravitational systems, and hence sprinklers are at the beginning of their life-cycle, the opposite should be true. This demonstrates that the coefficients cannot be interpreted at face value and that it is important to consider the underlying diffusion process when considering policy implications of an analysis.

The results show that water price is not the most important factor governing irrigation technology adoption; physical and agronomic characteristics appear to matter more. As a result, the distributional impacts of irrigation water pricing reforms will be significant, with changes in producer welfare following the spatial distribution of environmental characteristics. To the extent that micro-level factors condition irrigation technology choice, policies that change the price of irrigation water to reflect its off-farm value will result in a pure loss for some producers while encouraging adoption of modern irrigation technologies for other producers. This demonstrates the importance for economists to bear in mind the equity implications of water pricing reform proposals when interacting with decision makers.

This study has important implications for the design of water pricing and delivery policies. The statistical results of the model show that large increases in the price of water generally stimulate the adoption of drip irrigation systems; that adoption patterns are heavily influenced by crop type; and that the adoption decision is also strongly conditioned by slope, but is only slightly affected by variations in water-holding capacity. These results are a significant departure from previous studies which have generally failed to account for differences in adoption behavior within the group of pressurized technologies, which have failed to account for the influence of crop type on adoption behavior, and which have inadequately measured physical characteristics and water prices by relying on regional data.

The study clearly shows that microparameters are crucially important to understanding agricultural technology adoption and can best be statistically assessed using micro-level data. Since many of the important microparameters concern environmental conditions, the study also shows the value of integrating economic and environmental data when predicting grower behavior. Much relevant environmental data, (e.g., soil characteristics, microclimate, and cropping patterns) can be captured on a Geographic Information System (GIS). Fortunately, GIS systems are increasingly common and are decreasing in price, so that there are good prospects for incorporating environmental conditions when performing highly disaggregated analyses of agricultural technology choices.

Finally, it is important to note that this study supports the finding that heterogeneity of asset quality is critical in the general study of technology adoption. One of the major contributions of past studies of agricultural technology adoption to the general adoption literature is that they emphasize the role of heterogeneity of asset quality in the adoption process (Bellon and Taylor, Perrin and Winkelmann). Heterogeneity is a crucial element of the threshold model of diffusion (Davies, Stoneman and Ireland), but many of the early threshold models focus exclusively on variations in wealth or related factors such as farm size. The agricultural technology problem highlights the importance of differences in physical or geographical conditions in explaining adoption behavior and points out that geographic information must be combined with economic data to accurately predict adoption patterns.

*[Received April 1995; final revision received September 1996.]*

C-097395

C-097395

## 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.


C—097396

C-097396