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Land Allocation, Soil Quality, and the Demand for Irrigation Technology

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Economists have long argued that increasing the price of agricultural water will encourage the adoption of efficient irrigation technologies. This article considers the choice of irrigation systems conditional on prior land allocation decisions. Adoption functions for gravity and low-pressure irrigation technologies are estimated for citrus and vineyard crops using a field-level data set from California's Central Valley. Results show that the influence of land quality and water price on low-pressure technology adoption is greater for citrus than for vineyard crops. Consequently, the response of growers to changes in policy will be conditional on land allocation.

Key words: irrigation technology adoption, land quality, water policy

Introduction

Agricultural water use in important watersheds such as the Columbia basin and California's Central Valley has reduced instream flows and the generally poor quality of return flows has reduced instream water quality. Because the public highly values instream water quality, federal and state agencies are seeking to reallocate water from agriculture to instream flows. Further pressure to reduce agricultural water use is coming from the water demands of the rapidly expanding urban areas of the western states.

Economists have long argued that increasing water prices can encourage agricultural water conservation, and consequently, many irrigation water pricing policies have been changed to reflect this. For example, growers in California receiving water from the Central Valley Project (CVP) currently pay a restoration surcharge to fund capital improvements (such as fish screens on pumps), increase water flows for fish populations, and to restore wetlands. CVP water users also must pay the full contract cost of irrigation water on a portion of water received, where previously they only paid a fraction of the contract cost. Water purchase programs in California and Nevada's Lahontan Valley now procure water from willing farmers for environmental uses. In Nevada's Truckee River basin, the Reno/Sparks municipal water utility purchases agricultural water rights to dilute urban return flows (Sunding, Ise, and Millock). Such efforts to increase the price of agricultural water will likely intensify as water demand increases in the western states and as the public value of instream water quality increases.

Adopting efficient irrigation technologies is one potential response to an increase in

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the price of water. This particular response is favored by analysts and policymakers, most likely because technological change provides water savings, while maintaining agricultural output and employment. Technological change, thus, could resolve one of the most difficult political-economic problems associated with improving instream water quality: the perception that there is an inherent trade-off between environmental quality and jobs.

An extensive literature on irrigation technology adoption has shown both theoretically and empirically that the technology adoption decision depends on water price and land quality. Caswell and Zilberman (1986) show theoretically that the adoption decision is affected by well depth (i.e., water price), land quality, and crop type. Though the empirical literature supports many of the theoretical results (Cason and Uhlaner; Caswell and Zilberman 1985; Green et al.; Negri and Brooks; Nieswiadomy), the interdependent effect of water price, land quality, and crop type on irrigation technology choice has not been examined empirically. For example, Caswell and Zilberman (1986) demonstrate theoretically that when soil quality is sufficiently high, increases in the depth to groundwater will not induce adoption of low-pressure irrigation technologies. This relationship has important implications for policy design and should be examined empirically. The relative importance of land quality and water price to the adoption decision for different crops will determine the effectiveness of water price as a policy tool for inducing irrigation technology adoption and, ultimately, water conservation.

In many cases, growers of different crops cannot respond to increases in water price in the same manner. Growers of some crops have few effective responses to changes in water price, and consequently, the impact of an increase in the price of water may be to lower profits by the amount of the increase in water price with no reduction in water use. Other growers produce crops that cope well with changes in water application methods and can change technologies in response to water price increases. In this case, the reduction in profits will be smaller than the increase in water costs, especially if there are yield benefits from adopting low-pressure irrigation technologies. These differences in response can be attributed to the differential effect of land quality, biological needs, and water price on technology adoption for different crops and are important to understanding the distribution of policy impacts from changes in water price.

Agronomic factors diminish the effectiveness of water price as a policy tool in some cases and enhance it in others. Thus, changes in water use and the impacts of water policy changes are influenced by the distribution of land allocation and land quality. If irrigation technology adoption is conditioned on crop choices, then estimating technology adoption functions without controlling for land allocation decisions will lead to biased estimates of the water price elasticity. In an effort to more accurately characterize the relationship between water price and the demand for irrigation technology, we estimate distinct adoption functions for gravity and low-pressure irrigation technologies for citrus and vineyard crops. Comparing the adoption equations allows us to quantify the differential effect of land quality and water price on technology choice.

This article measures how changes in the price of water affect the choice of irrigation technology used by farmers in California's Central Valley. An important contribution of the study is that grower response to changes in water price is disaggregated by crop type. Our study is the first of which we are aware to model technology choice as conditional on both land allocation among crops and local environmental conditions such as land quality. The results of our study contribute to a more complete understanding of the "horizontal" or distributional impacts of changes in water price and improve upon previous results in the irrigation technology adoption literature.

Discrete choice models are used to estimate the probability of adopting irrigation technologies and measure the effect of water price and land quality on irrigation technology adoption. A cross-sectional field-level data set is used to estimate these relationships. Results show that the influence of land quality and water price on low-pressure technology adoption is greater for citrus than for vineyard crops. Consequently, the response of growers to changes in policy will be conditional on land allocation.

Empirical Model

The adoption decision depends on the profitability of crop production, π_{ij}, under the *i*th irrigation technology on the *j*th field. The theoretical and empirical literature on technology adoption has shown that the profitability of production under a given technology is influenced by a vector of field characteristics, X, including the price of water, ω, which varies across fields. Thus, when considering the irrigation adoption decision, perceived profit, $\pi_{ij}(X)$, is a function of field characteristics and water price.[1] For a grower to consider adopting a modern low-pressure irrigation technology the perceived profits under the *i*th technology must be at least as large as those under the traditional gravity technology, $\Delta\pi = \pi_{ij} - \pi_{0j} > 0$, where $i = 0$ denotes the gravity technology. Further, for water-pricing policy to encourage adoption of low-pressure irrigation, changes in water price must increase the profit differential between the alternative technologies (i.e., $\partial\Delta\pi(X)/\partial\omega > 0$). Unfortunately it is not possible to determine how changes in water price will affect the profit differential theoretically, and so the effect must be determined empirically.

The grower is assumed to maximize expected utility by selecting the irrigation technology with the highest perceived profits, given by $\pi_{ij}(X) = f_{ij}(X) + \epsilon_{ij}$. Here $f_{ij}(X)$ is a nonstochastic function of field characteristics (including water price) and ϵ_{ij} is a scalar that represents unobserved characteristics. Rather than estimate the perceived profits directly, discrete choice models can be used to estimate the probability of adopting a given technology as a function of field-level variables. This implies that the higher the probability of adoption for a given technology, the larger the perceived profits are for that technology. We assume that $f_{ij}(X)$ takes the form $\beta_i' X_j$, where β_i is a parameters vector associated with the irrigation technology and X_j is a vector of observed field characteristics and water price. Because we are interested in the profit difference between the low-pressure and gravity irrigation technologies it is necessary to assume a distribution for difference between the ϵ_{ij}s. Assuming that the ϵ_{ij}s are random independent variables with a Weibull distribution, the distribution of the difference between the ϵ_{ij}s is logistic (Domencich and McFadden). We focus on the adoption of two groups of irrigation technologies: low pressure, which includes drip and microsprinkler; and gravity, which is the traditional or base technology. This reduces the model to a binomial logit that relates the probability of choosing the low-pressure technology to the characteristics of the field. To remove an indeterminacy in the model the β_0s are normalized to equal zero. Conse-

[1] For a complete theoretical development of production profits when considering adoption of alternative irrigation technologies see Caswell and Zilberman (1986). Also, variables that do not vary by field in the cross-sectional data set, such as crop price, are not included in the profit function for this analysis since they would be the same for each observation.

Table 1. Mean and Standard Deviation of Variables

Variable	Citrus		Vineyard	
	Mean	SD	Mean	SD
Water price ($/ac.-ft.)	56.06	8.20	54.20	10.42
Soil permeability (in./hr.)	2.21	3.35	3.77	3.23
Field gradient (%)	2.56	1.64	1.32	1.02
Field size (acres)	44.23	61.73	55.42	53.51
Surface water (0/1)[a]	0.61	—	0.37	—

[a] The mean represents the percentage of fields that are able to get surface water. Consequently, the standard deviation is not relevant.

quently, the irrigation technology index i is no longer necessary. The probability that the low-pressure irrigation technology is adopted on the jth field is given by[2]

$$(1) \qquad P_j = \frac{1}{1 + e^{-\beta' X_j}}; \qquad j = 1, 2, 3, \ldots, J.$$

To demonstrate the interrelated effect of land quality and water price on irrigation technology choice for a specific crop, data were collected from the Arvin-Edison Water Storage District (district), which is in the southern San Joaquin Valley of central California. There is a wide variation in irrigation technologies, topography, and soil types within the district. We focus on citrus and vineyard crops, both perennials that have historically used similar irrigation technologies. This allows us to show that even for similar crops land quality and water price do not affect technology choice in the same manner. Vineyard crops in the district are mostly table grapes and citrus crops include oranges, grapefruit, lemons, and limes. The data on irrigation technology, field size, water price, and water source were collected by district employees for their annual crop reports. This analysis is based on data from the 1993 growing year (table 1). Only 3 of the 274 citrus observations and 4 of the 423 vineyard observations use high-pressure sprinkler systems. Consequently, the observations using high-pressure sprinklers were removed from the data set and the irrigation choice is between gravity and low-pressure systems. Otherwise, all citrus and vineyard crops grown in the district are included in the data set.

Whether surface water, groundwater, or both are available on a given field depends on where in the district the field is located. If a field has access to high quality groundwater it may not be able to receive surface water, only 61% of the fields in our sample receive surface water. The energy cost for pumping groundwater is assumed to be the marginal price of water for growers that do not have access to surface water. Pumping cost 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, and ranges from $40 to $88 per acre-foot. The per acre-foot charge of the district's water rate is used as the marginal price of water for fields that have access to surface water. Though the marginal price of

[2] This specification of the binomial logit model assumes that the critical independent variables are included in X. If this assumption is violated, the estimates of β will be inefficient and the standard deviations will be underestimated (Amemiya and Nold). However, to correct for specification error as suggested in Amemiya and Nold, it is necessary to have a panel data set, which unfortunately, is not available.

Table 2. Estimation Results for Low-Pressure versus Gravity Irrigation Systems on Citrus and Vineyard Crops

	Citrus		Vineyard	
Variable	Coefficient	*t*-ratio	Coefficient	*t*-ratio
Constant	−9.667	−5.613	−2.350	−2.801
Water price ($/ac.-ft.)	0.138	4.735	0.002	0.115
Soil permeability (in./hr.)	0.086	1.551	0.067	1.902
Field gradient (%)	0.985	5.324	0.520	4.202
Field size (acres)	0.017	2.740	0.004	2.125
Surface water (0/1)	0.719	1.966	0.537	2.107
Observations	271.00		419.00	
R^2	0.35		0.12	
Likelihood ratio test: χ^2_5	100.15		47.19	
Correct predictions	80%		74%	

groundwater is about $25 per acre-foot more than that of surface water, the fixed component of the district's charge for surface water is set so that the total price for ground- and surface water are approximately equal, ranging from $50 to $110 per acre-foot. The range in water price throughout the district stems from variation in elevation.

The Kern County Natural Resource Conservation Service collected data on soil permeability and field slope, which are used to define land quality. The land quality data are specified for each quarter section, which is a 160-acre plot. District land maps were used to match each field to its respective quarter section. Permeability and slope were given in inches per hour and percent, respectively. Both permeability and slope were given in ranges, and the midpoint was taken and used to construct weighted averages for each quarter section.

There are five explanatory variables: four continuous variables, (*a*) price of water, (*b*) soil permeability, (*c*) field slope, and (*d*) field size; and one binary variable, which is water source (i.e., groundwater or both ground- and surface water). Table 1 shows that there is substantial variation in the explanatory variables. Irrigation technology is the dependent variable and the gravitational technology is used as the benchmark technology for both of the citrus and vineyard models. To quantify the effect of field characteristics and water price on irrigation technology choice, the data are used to estimate the logit models. The probability of adoption and the marginal effects of each variable are also calculated.

Estimation Results

The estimation results show that the citrus model has a better fit than the vineyard model, although both models perform well (table 2). To measure the performance of the models the R^2, the likelihood ratio test, and the percentage of correct predictions are reported. Each of these measures is given since no single measure alone is reliable for describing a qualitative choice model's performance (Maddala). The vineyard equation has a low R^2, though this is not unusual for qualitative choice models. It has been shown that

Table 3. Probabilities and Elasticities of Adoption for Citrus and Vineyard Crops

Variable	Citrus		Vineyard	
	Gravity	Low Pressure	Gravity	Low Pressure
Probability of adoption	0.13	0.87	0.71	0.29
Water price ($/ac.-ft.)	(−6.65)	(1.01)	(−0.03)	(0.07)
Soil permeability (in./hr.)	(−0.16)	(0.02)	(−0.07)	(0.18)
Field gradient (%)	(−2.19)	(0.33)	(−0.20)	(0.49)
Field size (acres)	(−0.64)	(0.10)	(−0.07)	(0.17)
Surface water (0/1)	[−0.06]	[0.06]	[−0.11]	[0.11]

Note: Terms in parentheses are elasticities. Terms in square brackets are the percent change in the probability of adoption as the discrete variable changes from 0 to 1.

obtaining a low R^2 when calculating the correlation between a binary dependent variable and the corresponding predicted probability does not imply that the model is a poor fit (Morrison). Since the likelihood ratio test and the percentage of correct predictions both show a good fit for the vineyard model, the low R^2 is not given much weight in judging the model's performance. All of the measures of performance show that the citrus model performs well.

The most striking difference between the citrus and vineyard models is the effect of water price on irrigation technology adoption. While the coefficient on the water price variable for citrus crops is very significant, the water price coefficient on vineyard crops is small and insignificant. This is interesting since both crops face a similar average price of water per acre-foot and historically have experienced similar changes in the water price. This result demonstrates that the effectiveness of water price as a policy tool may be conditional on previous land allocation decisions. The other variables have similar effects on the coefficients of adoption of low-pressure systems for both citrus and vineyard crops. Though the coefficients of the citrus model are larger in magnitude than those of the vineyard model, they are of similar significance. This is somewhat surprising given that, on average, citrus crops are grown on fields that have a higher gradient and lower permeability than fields with vineyard crops. To make an easier comparison between the effect of the variables on the probability of adoption for citrus and vineyard crops, the probabilities and elasticities of adoption are given in table 3. The citrus model tends to overpredict the probability of adoption for low pressure, and the vineyard model slightly underpredicts the probability of adoption for low pressure, as compared with the observed proportions of low-pressure technologies. This occurs because the field size and soil permeability variables in the citrus data have a skewed distribution and the probability of adoption is evaluated at the mean of the variables. Water price and field slope have the largest elasticities and the most significant effect on technology choice in citrus crops. This may be explained by the fact that a large percentage of the citrus acreage is in the foothills of the district and at a higher elevation than the valley floor. This reduces the chance of freezing, but results in a larger field gradient and slightly higher water price since it has to be lifted higher. Thus, a biological need of the crop indirectly results in the use of low-pressure irrigation.

For vineyard crops we find that gradient is an important determinant of technology adoption, even though the average gradient of vineyard acreage is only 1.32%. The elasticity shows that a 1% increase in the gradient results in almost 0.5% increase in the probability that a low-pressure system will be adopted. Soil permeability is also important to technology choice in vineyard crops. In our sample vineyard crops had a high average soil permeability at 3.77 inches per hour, which is 73% higher than the average permeability of soils for citrus crops. Water price is not an important factor for technology adoption in vineyard crops. This finding may be explained by the fact that traditional vineyard growers believe that vines are more susceptible to disease when grown with low-pressure irrigation. A low-pressure system causes the vine to have a smaller root system than with a gravity system. This is not a problem with citrus crops because it is possible to use multiple emitters, which creates a larger root system. Consequently, some vineyard growers have hesitated to switch to low-pressure irrigation systems since they perceive this technology as a threat to the longevity of their crops, which have a high replacement cost. It is important to note, however, that 29% of the growers in the district have adopted low-pressure irrigation systems on vineyard crops and that this has just occurred during the last decade. As a result, the use of low-pressure irrigation systems on vineyard crops may be in the early stages of the diffusion process, and thus, as more growers adopt low-pressure systems on vineyard crops, the adoption decision may become more sensitive to water price.

The elasticities in table 3 show that the probability of adopting low-pressure systems in citrus crops increases as either water price, field gradient, or both increase. That is, on citrus fields with a high gradient, water price is more likely to be an effective policy tool. Further, because field gradient has a large negative elasticity of adoption for citrus crops we can infer that on fields with low gradient (i.e., high quality), a high water price will be necessary to induce adoption of a low-pressure irrigation technology. This confirms empirically what was shown theoretically in Caswell and Zilberman (1986). However, noting that the soil permeability elasticity is 10 times less than of the water price elasticity, it is likely that permeability would not have any effect on adoption at any level of price. Thus, different types of land quality relate to the effectiveness of water price as a policy tool differently.

Similar inferences cannot be made for vine crops since the statistical results are not as strong as those for citrus crops. The lack of sensitivity to changes in water price of vineyard relative to citrus crops may be partly due to vines in the district using 29% less water than citrus, 2.7 acre-feet per acre for citrus and 2.1 acre-feet per acre for vineyard (JMLord). It is important to note that adopting low-pressure technologies is the only response modeled, which will tend to underestimate reductions in water use due to increases in water price. Other responses may include crop stressing, increased water management, or refinement of the existing irrigation system. Growers that are more easily able to adopt low-pressure technologies will realize smaller profit losses as a result of increases in water price. Interestingly enough, over the last decade while vineyard acreage has remained relatively constant, citrus acreage has almost doubled. During this same time period marginal water price has also almost doubled.

Conclusions

We have modeled the adoption of low-pressure irrigation as a function of water price and field characteristics conditional on the decision to produce citrus and vineyard crops.

Though citrus and vineyard crops are both perennial crops that are grown with the same irrigation technologies, the agronomic factors motivating technology adoption are different for each crop. Adoption of drip irrigation on citrus crops is much more sensitive to changes in water price. Consequently, while increases in water price may lead growers to adopt water-saving technologies in citrus crops, adoption is less likely in vineyard crops. Thus the distribution of water policy impacts depend on prior land allocation decisions.

The distribution of policy impacts will also depend on the land quality of the specific field where a given crop is grown. For example, the probability of adopting low-pressure irrigation is lower on fields with high land quality since these fields may provide high irrigation efficiencies under traditional gravity technologies. That is, adoption is less likely to occur on a field that is relatively flat. Consequently, increases in water price may not justify adoption, resulting in a pure profit loss without reducing water use no matter what crop is grown. We do not suggest that water price is a poor policy tool. Rather, we argue that using price as a policy tool is similar to applying a uniform tax to an externality that varies by location. However, we have only examined changes in irrigation technology, which ignores the growers ability to increase the efficiency of the traditional gravity system. To the degree that increases in water price induce increases in the efficiency of existing systems, profit losses will be reduced.

Our results support the finding that heterogeneity of asset quality is critical in the general study of technology adoption (Bellon and Taylor; Perrin and Winkelmann). Because the irrigation technology adoption decision depends critically on crop type and land quality, it will be difficult to predict impacts of water price policies with models based on regional averages and aggregated data. This highlights the importance of incorporating 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 and the distribution of policy impacts.

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