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Abstract

Logit models are estimated for citrus and vineyard crops to show under what land quality conditions water price is an effective policy tool for inducing adoption of modern irrigation technologies, and how welfare impacts of water policy depend on cropping patterns and the distribution of land quality characteristics.

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

Introduction

During the last decade there has been a dramatic increase in the regulation of agricultural water use stemming from the increased demands on existing water supplies for urban and environmental purposes. Because development of additional water supplies has become politically unpopular and because agriculture uses over 80% of consumed water, it has been suggested that water be reallocated from agriculture to meet increases in demand. Economists have long recommended that policy makers use water price as a tool to encourage increases in water use efficiency to help mitigate the increase in water demand and reduce the impact of reallocation. The benefit of using water price as a policy tool, rather than a quantity control, is that it allows the grower a higher degree of flexibility to adjust to the change in policy. Since growers in a given region may produce different crops under different production conditions adjustments made to minimize the impact of a change in policy will differ for each grower, and consequently, some growers will be impacted more severely than others. The objective of this paper is to identify under what agronomic conditions investments in modern irrigation technologies will be made as a result of changes in water price and show that the distribution of policy impacts depends critically on the type of crop grown and the production environment.

There is an extensive literature on irrigation technology adoption that has shown both theoretically and empirically that the adoption decision depends critically on water price and land quality. Caswell and Zilberman (1986) showed theoretically that the adoption decision is effected by well depth (i.e. water price), land quality and crop type. Though the empirical literature supports these findings (Cason and Uhlaner; Caswell and Zilberman [1985]; Green et al.; Negri and Brooks; and 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) used comparative statics to demonstrate theoretically that when soil quality is sufficiently high, increases in the depth to ground water will not induce the adoption of modern irrigation technologies. Further, it has been shown that land quality is an important determinant of cropping patterns (Lichtenberg; and Plantinga) and that it is common to observe similar crops being grown on land with similar qualities. While soil permeability may be critical to the adoption of a technology for one crop, it may have only a small effect on adoption for an alternative crop. In fact, soil permeability may be so important that water price has only a small affect on technology adoption. Consequently, one would expect that the relative significance of land quality and water price in the adoption decision to vary by crop. This has important implications to the welfare effects of water pricing policy. The relative importance of land quality and water price to the adoption decision for different crops is truly an empirical question and will ultimately determine the effectiveness of water price as a policy tool for inducing irrigation technology adoption.

Agronomic factors place natural constraints on the adoption of irrigation technologies that may diminish the effectiveness of water price as a policy tool in some cases and enhance it in others. The result being that changes in water use and welfare impacts that result from water policy may follow the distribution of cropping patterns and land quality. Understanding the combined effect of water price, land quality and crop type will help predict grower response to water policy and estimate the distribution of welfare impacts as they relate to land quality and crop type. To isolate the relationship between land quality and water price we estimate adoption functions for gravity and drip irrigation technologies on citrus and vineyard crops, which allow us to quantify the differential effect of land quality and water price on technology choice. Discrete choice models are used to estimate the probability of adoption of irrigation technologies and quantify the interactive effects of water price and land quality variables on the adoption decision. A cross-sectional field-level data set is used to estimate these relationships. The results of the study are discussed and shown graphically, we conclude by highlighting the important policy implications of the study.

Empirical Model

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

The grower is assumed to maximize expected utility by selecting the irrigation technology with the highest perceived profits, given by $\pi_{ij}(\boldsymbol{X}) = f_{ij}(\boldsymbol{X}) + \varepsilon_{ij}$. Here $f_{ij}(\boldsymbol{X})$ is a nonstochastic function of field characteristics and 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 $f_{ij}(\boldsymbol{X})$ takes the form $\boldsymbol{\beta}_i'\boldsymbol{X}_j$, where $\boldsymbol{\beta}_i$ is a vector of estimable parameters associated with the irrigation technology and $\boldsymbol{X}_j$ is a vector of observed field characteristics and water price. Because we are interested in the profit differential between the modern and traditional irrigation technologies it is necessary to make an assumption on the distribution of the

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[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.

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 micro-sprinkler; and gravity, which is considered the traditional or base technology, and includes furrow, border and flood irrigation. 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 $\boldsymbol{\beta_0}$'s are normalized to equal zero. Consequently, the irrigation technology index *i* is no longer necessary. The probability that the low-pressure irrigation technology is adopted on the *j*th field is

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

To demonstrate the inter-related effect of land quality and water price on irrigation technology choice for a specific crop, data was collected from the Arvin-Edison Water Storage District (the District), which is located in the southern San Joaquin Valley in 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 effect technology choice in the same manner. Vineyard crops in the District are almost exclusively different varieties of table grapes and citrus crops are oranges, grapefruit, lemons and limes. The data on irrigation technology, field size, water price, and water source were collected for the 1993 growing year by the District (Table 1). Citrus and vineyard crops are grown almost exclusively with flood and drip irrigation. In fact, only 3 of the 274 citrus observations and 4 of the 423 vineyard observations use high-pressure sprinkler systems. Consequently, the observations with high-pressure sprinkler were removed from the data set and the irrigation choice for these crops was modeled to be between flood and drip systems. Otherwise, all citrus and vineyard crops grown in the District are included in the data set.

Whether surface water, ground water 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 ground water it may not be in the District's service area and is not able to receive surface water. Only 61% of the fields in our sample receive surface water.[2] The energy cost for pumping ground water 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 ground water 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 variable component 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 ground water is about $25 per acre-foot more than that of surface water, the fixed component of the District 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 through out 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; (i) price of water, (ii) soil permeability, (iii) field slope, and (iv) field size, and one binary; (v*)* water source (i.e., ground water or both ground and surface water). Table 1 shows that there is substantial variation in

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[2] Because growers in the District rely heavily on ground water to irrigate crops it is necessary for the District to operate a conjunctive use system. In fact, one of the primary charges of the District is to recharge the ground water aquifer with imported surface water.

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 is 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, though 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 model's performance (Maddala). The vineyard model has a low R^2, though this is not unusual for qualitative choice models. It has been shown that obtaining a low R^2 when calculating the correlation between a binary dependent variable and the corresponding predicted probability may 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 for the citrus model show that the model performs well. However, we do note that the citrus model tends to over predict the adoption of drip, while the vineyard model slightly under predicts the adoption of drip.

The most striking difference between the citrus and vineyard results is the effect of water price on the 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 vary substantially depending on cropping patterns. Which has important implications to the distribution of welfare impacts of water pricing policy.

The other variables have similar effects on the coefficients of adoption of low-pressure systems for both citrus and vineyard crops. Though the coefficients on citrus are larger in magnitude then those on vineyard, 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. Water price and field slope have the largest elasticities and most significant effects on technology choice in citrus crops. 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 percent. The elasticity shows that a one percent increase in the gradient results in almost a half percent 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 the highest average soil permeability at 3.77 inches per hour, which is 73 percent 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 vineyard growers believe that vines are more susceptible to disease when grown with drip irrigation. The use of a drip system causes the vine to have a smaller root system than the use of a gravity system. Though there is some antidotal evidence of this, it has not been shown conclusively. This is not a problem with citrus crops because it is possible to use multiple drip emitters, which creates a larger root system. Growers have begun experimenting with low-pressure sprinklers on vine crops, though this may increase moisture on the fruit and cause decay. Consequently, many vineyard growers are not willing to switch to low-pressure irrigation since they perceive this technology as a threat to the longevity of their crops which have a high cost of replacement. In such a case, the use of water price as a policy tool would most likely not induce adoption of low-pressure systems.

For a better understanding of the effectiveness of water price as a policy tool to induce irrigation technology adoption in different crops and in the presence of varying land quality we graphed the probability of adoption as a function of the water price and land quality variables. We choose to examine the effect of these variables since they have been found to be the most important in the existing literature and are the focus of this analysis. Figures 1 and 2 show iso-probability lines for citrus crops, pairing water price with each of the land quality variables[3]. The effect of land quality and water price on adoption is found by varying the level of the variables for each model while holding the probability of adoption constant. As is standard, we assume that adoption occurs when the probability of adoption is greater than 0.5 (Greene). In Figure 1 we show that the probability of adoption for low-pressure systems in citrus crops increases as either water price, field gradient, or both increase. That is, on citrus fields that have a high gradient, water price is more likely to be an effective policy tool. However, in Figure 2 we show that soil permeability has very little effect on the effectiveness of water price as a policy tool. That is, in citrus crops water price is equally effective for all levels of soil permeability. In both Figures 1 and 2 it takes a substantial change in water price to increase the probability of adoption from 0.75 to 0.99[4], which indicates that the elasticity of adoption with respect to water price decreases as price increases. This implies that in areas that already have high water prices there will be a smaller response to increases in water price, as compared to areas that have lower water prices.

Different levels of water price were simulated to demonstrate the effect of water price on irrigation technology adoption and water use for citrus and vineyard crops (Figure 3). Adoption in citrus is much more sensitive to variation in water price than in vineyard crops,

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[3] Similar figures for vines are not shown to conserve space. The vineyard figures showed that water price has almost no effect on technology adoption when compared to field gradient and very little effect when compared to soil permeability.

[4] The probability of 0.99 is used rather than a probability of 1.0 because using 1.0 results in a division by zero.

demonstrating that other variables are more critical to the adoption decision in vineyard crops. The lack of sensitivity to changes in water price of vineyard relative to citrus crops may in part be due the fact that the consumptive water use of vines in the District is 29% less than that for citrus, 2.7 acre-feet per acre for citrus and 2.1 acre-feet per acre for vineyard (JMLord). To estimate the change in water use from increases in water price it is assumed that flood irrigation has a 70% efficiency and that drip has a 87% efficiency (Sanden and Hockett), so adoption produces a 24% increase in irrigation efficiency. It is important to note that adoption of drip technologies is the only response modeled, which will tend to under estimate 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. However, our results demonstrate that the demand for low-pressure irrigation technologies for these crops is influenced by the presence of different field characteristics, and as a result welfare impacts of water price policy will depend on cropping patterns and physical production conditions. Growers that are able to 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 drip irrigation technologies as a function of water price and field characteristics contingent 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 pattern and impetus of technology adoption for each is quite different. Citrus crops are much more sensitive to changes in water price. Consequently, while increases in water price may lead to the adoption of water saving technologies in citrus crops that reduce policy impacts to citrus growers, adoption is less likely in vineyard crops and growers will bear a relatively larger portion of the welfare loss. This implies that welfare impacts from water policy may depend critically on cropping patterns.

The distribution of welfare impacts will also depend on the land quality of the specific field a given crop is grown on. The probability of adoption of low-pressure irrigation technologies is lower on fields that have higher land quality since these fields may give rise to high irrigation efficiencies under traditional gravity technologies. For example, 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 lose without a reduction in water use no matter what crop is grown. We do not suggest that water price is a poor policy tool. Rather, we show that using price as a policy tool is similar to applying a uniform tax to an externality with spatial variation, thereby causing unnecessary deadweight loss. 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, the deadweight loss 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; and Perrin and Winkelmann). Because the irrigation technology adoption decision depends critically on crop type and land quality it will be difficult to predict welfare 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 welfare impacts.

Table 1: Mean and Standard Deviation of Variables

	Citrus		Vineyard	
Variable	Mean	Standard Deviation	Mean	Standard Deviation
Water price ($/acre-foot)	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)	0.61	--	0.37	--

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

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 ($/acre-foot)	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		419	
R^2	0.35		0.12	
Likelihood ratio test: χ^2_5	100.15		47.19	
Correct prediction	80%		74%	

Table 3: Probabilities and Elasticities* of Adoption for Citrus and Vineyard Crops

	Citrus		Vineyard	
Variable	Gravity	Low-Pressure	Gravity	Low-Pressure
Probability of Adoption	0.13	0.87	0.71	0.29
Water price ($/acre-foot)	(-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]

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

Figure 1: Iso-Probability Lines for Citrus: Field Gradient versus Water Price

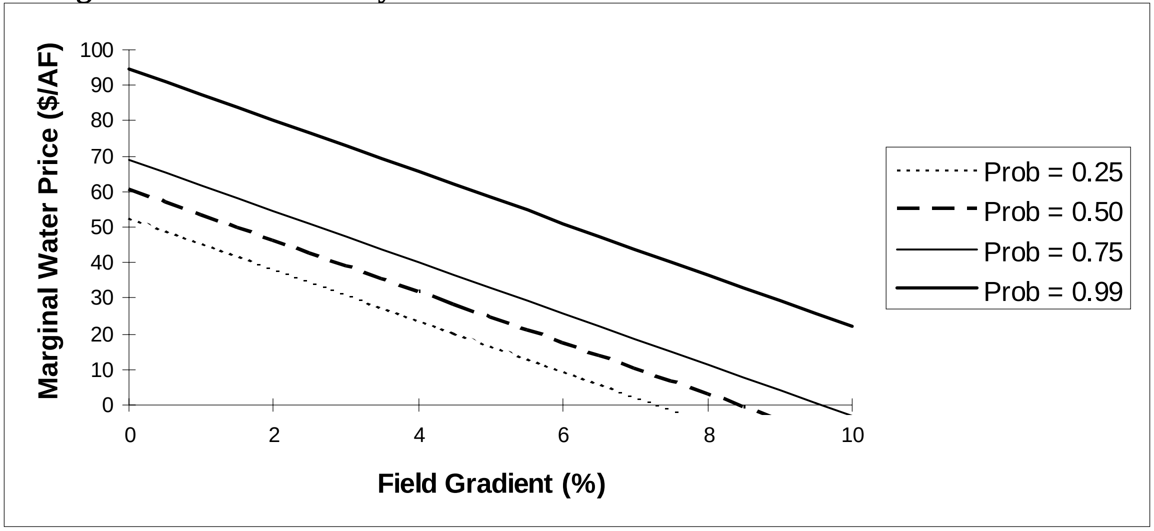


Figure 2: Iso-Probability Lines for Citrus: Soil Permeability versus Water Price

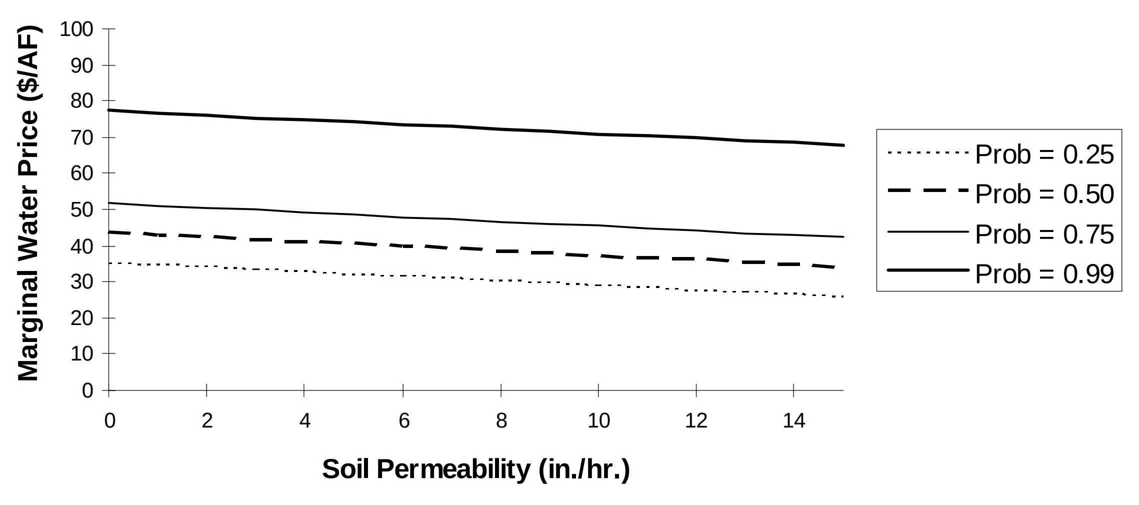
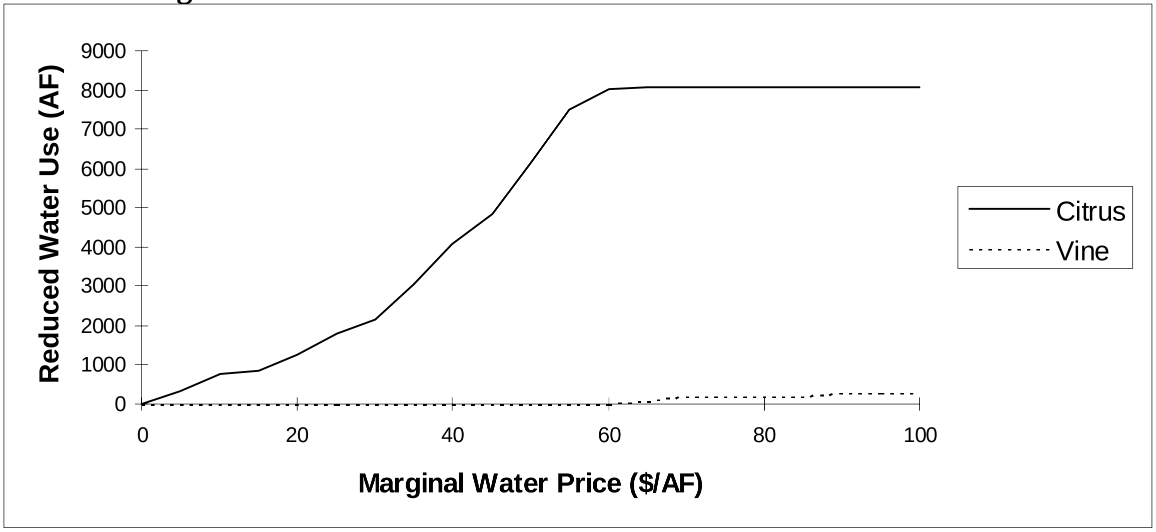


Figure 3: Reduction in Water Use for Increases in Water Price



References

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

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

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

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

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

Green, G., D. Sunding, D. Zilberman, and D. Parker. "Explaining Irrigation Technology Choices: A Microparameter Approach." *Amer. J. Agr. Econ.* 78(1996)1064-72.

Greene, W., *Econometric Analysis, second edition*. Englewood Cliffs: Prentice Hall, 1993.

JMLord, Inc. "Arvin-Edison Water Storage District Assessment of Reasonable Water Requirements." *Technical Report*. Fresno, 1994.

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

Maddala, G. *Limited-Dependent and Qualitative Variables in Econometrics*. Cambridge: Cambridge University Press, 1987.

Morrison, D.G. "Upper Bounds for Correlations Between Binary Outcomes and Probabilistic Predictions." *J. Amer. Stat. Assoc.* 7(1972):68-70.

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

Nieswiadomy, M. "Input Substitution in Irrigated Agriculture in the High Plains of Texas, 1970-80." *West. J. Agr. Econ.* 13(1988):63-70.

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

Plantinga, A. “The Effect of Agricultural Policies on Land Use and Environmental Quality.” *Amer. J. Agr. Econ.* 78(1996)1082-91.

Sanden, B., and B. Hockett, “Irrigation Uniformity and Efficiency in Kern County,” *Kern County Cooperative Extension Bulletin*, Bakersfield, CA.