Appendix 7

Under What Conditions Does Water Price Encourage Irrigation Technology Adoption?

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by

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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. Reallocation of water from agriculture to meet increases in demand has been suggested because agriculture uses over 80% of consumed water and because the development of additional water supplies has become politically unpopular and cost prohibitive. 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. 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 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 influence of these variables 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.

The Model

The adoption decision is based on the grower's perceived 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, 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, $\pi_{ij}(X)$.[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. $M\Delta\pi(X)/M\omega > 0$). 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 $\pi_{ij}(X) = f_{ij}(X) + \varepsilon_{ij}$. Here $f_{ij}(X)$ 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 $f_{ij}(X)$ takes the form $\beta_i N X_j$, where β_ι is a vector of estimable parameters 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 differential between the modern

[1] For a complete theoretical development of production profits when considering adoption of alternative irrigation technologies see Caswell and Zilberman (1986).

and traditional irrigation technologies it is necessary to make an assumption on the distribution of the difference between the ε_{ij}'s of the technologies. 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. To remove an indeterminacy in the model the β_0's are normalized to zero. The probability that the low-pressure irrigation technology is adopted on the jth field is given by

(2) $; j = 1, J.$

This is a binomial logit model that relates the probability of choosing the low-pressure technology to the characteristics of the field.

Data

To estimate the interaction 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) located in the southern San Joaquin Valley in Central California. The District was established in the early 1940's to contract for surface water to reduce demands on the local ground water supplies. There is a wide variation in crops, irrigation technologies, topography and soil types within the District; yet, the area is relatively small so the growers participate in many of the same markets and institutions. This makes the District ideal for analysis.

We focus on vineyard and citrus crops, both perennials that have historically used similar irrigation technologies. This will allow us to show that even for similar crops land quality and water price do not effect technology choice in the same manner. The data are from the 1993 growing year. The data on crop type, irrigation technology, water price, and water source were collected by the District. Ground water pumping cost, which is the marginal price of ground water, is estimated by the District based on depth of ground water 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, which on average is $25 less per acre-foot than ground water pumping costs. Growers in the District pay relatively high marginal price for water; in 1993 the price ranged from $12 to $57 per acre-foot for surface water and $40 to $88 per acre-foot for ground water. However, the fixed component of the District charge for surface water is adjusted so that the total price for ground and surface water are approximately the same, ranging from $50 to $110 per acre-foot. The range in price stems from the variation in elevation within the District.

The Kern County Natural Resource Conservation Service (formerly the Soil 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. To match the quarter sections 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 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.

In the District citrus and vineyard crops are grown almost exclusively with flood and drip irrigation. In fact, in our sample only 3 of the 274 citrus observations and 4 of the 423 vineyard observations use high-pressure sprinkler systems. As a result, we modeled the irrigation choice for these crops to be between flood and drip systems.

There are five variables: four continuous; (a) price of water, (b) soil permeability, (c) field slope, and (d) field size, and one binary; (e) water source (i.e., ground water or both ground and surface water). Without loss of generality, the gravitational technology is used as the benchmark for technology choice for both statistical models. To quantify the effect of cropping patterns on irrigation technology choice, the discrete choice models are used to estimate the coefficients. The probability of adoption and the elasticities for each variable are also calculated.

Results

The statistical package Limdep 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 models in Table 1. To allow comparison of adoption rates among gravitational and drip technologies, we calculate the probability of adoption, the elasticity of the continuous variables, and the change in probability of the discrete variable if it were to change from 0 to 1 (Table 2).

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_Ω is the unrestricted maximum log-likelihood and L_ω 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 percent of correct predictions is calculated as the total number of correct predictions as a percent of the number of observations. Each of these measures is given since no single measure alone is reliable for describing the model's performance (Maddala).

The estimation results for the citrus and vineyard models given in Table 1 show that the citrus model has a better fit than the vineyard model, but that both models perform well. The citrus model tends to over predict adoption of drip, while the vineyard model tends to under predict adoption of drip. The most striking difference between the results for citrus and vineyard crops is the effect of water price on the probability of irrigation technology adoption. While the coefficient on the water price variable for citrus crops is highly significant, the water price coefficient on vineyard crops is small and insignificant. This is surprising since both crops face an average price of $55 per acre-foot and historically have experienced similar levels of water price. The other variables have similar effects on the probability of adoption for both citrus and vineyard crops. Though the coefficients on citrus are larger then those on vineyard, they are of similar significance. A dummy variable is used to indicate the use of surface water on a given field. The coefficient was expected to be positive because much of the District's delivery system is pressurized, and as a result, it is less expensive to operate a drip system with surface water. The positive coefficients were also expected on field slope, soil permeability, and field size.

To give an easier comparison between the effect of the variables on citrus and vineyard crops, the probabilities and elasticities of adoption are given in Table 2. Water price and field slope have the largest and most significant effects on technology adoption in citrus crops, for which there are several explanations. First, a large percentage of the citrus acreage is in the foothills of the District and are at a higher elevation than the valley floor. This reduces the chance of freezing and also results in a higher price of water since it has to be lifted higher. Thus, a biological need of the crop results in the use of expensive water and induces the adoption of drip irrigation. Second, the average field gradient for citrus crops in the District is 2.6 percent, so there is a greater chance of runoff and erosion if gravity irrigation is used. The use of drip irrigation eliminates these problems and gives a more uniform application of water.

For vineyard crops we find that slope is an important determinant of technology adoption, even though the average slope of vineyard acreage is only 1.3 percent. Soil permeability is also important to technology choice in vineyard crops. In our sample vineyard crops had the highest average soil permeability at 3.8 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

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grown with drip irrigation. Though there is some antidotal evidence of this, it has not been shown conclusively. Consequently, the use of water price as a policy tool would most likely not induce many vineyard growers to switch to drip irrigation since growers perceive this technology as a threat to the longevity of their crops, which have a high cost of replacement.

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. Figures 1 though 4 show iso-probability lines for citrus and vineyard crops, pairing water price with each of the land quality variables. 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 probabilities constant. In the logit model adoption occurs when the probability of adoption is greater than 0.5. In Figure 1 we show that the probability of adoption for 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 1, 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.

Table 1: Estimation Results for Drip Irrigation on Citrus and Vineyard Crops

Variable	Citrus		Vineyard	
	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
Surface water (0/1)	0.719	1.966	0.537	2.107
Soil permeability (in./hr.)	0.086	1.551	0.067	1.902
Field slope (%)	0.985	5.324	0.520	4.202
Field size (acres)	0.017	2.740	0.004	2.125
Observations	271		419	
McFadden R^2	0.32		0.09	
Likelihood ratio test:	100.15		47.19	
Correct prediction	80%		74%	

Table 2: Probabilities and Elasticities[a] of Adoption for Citrus and Vineyard Crops

Variable	Citrus		Vineyard	
	Flood	Drip	Flood	Drip
Probability of Adoption	0.13	0.87	0.71	0.29
Water price ($/acre-foot)	(-6.65)	(1.01)	(-0.03)	(0.07)
Surface water (0/1)	[-0.06]	[0.06]	[-0.11]	[0.11]
Soil permeability (in./hr.)	(-0.16)	(0.02)	(-0.07)	(0.18)
Field slope (%)	(-2.19)	(0.33)	(-0.20)	(0.49)
Field size (acres)	(-0.64)	(0.10)	(-0.07)	(0.17)

[a]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.

Figures 3 and 4 show the relationship between water price and land quality variables for vineyard crops. Figure 3 shows that water price has almost no effect on the probability of adoption of drip in vineyard crops relative to field gradient. Note that the probability of adoption does not equal 1 for the ranges of field gradient found in the District. Figure 4 shows that water price does influence the probability of adoption relative to soil permeability, but not to a large extent. However, in Figure 4 the

highest probability of adoption is 0.45 for the range of soil permeability found in the District. Based on Figures 3 and 4, one would suspect that there is a critical combination of variables that lead to the adoption of drip in vineyard crops, rather than the presence of one specific variable as might be the case in citrus crops.

Increases in water price were simulated to investigate the effect of water price on irrigation technology adoption and water use for citrus and vineyard crops. Adoption in citrus was much more sensitive to increases in water price than 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 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). The change in water use as a function of increases in water price is shown in Figure 5. 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. Figure 5 shows the water savings that could be achieved in the District if price increases were to lead to additional technology adoption. Note that reductions in water use for citrus reaches it maximum at $15, which marks 100% adoption of drip in citrus crops. Increases in price do not have nearly the same effect on adoption in vineyard crops, demonstrating that other variables are more critical to the adoption decision.

Conclusions

We have modeled the adoption of drip irrigation technologies as a function of water price and land quality for citrus and vineyard crops. Though citrus and vineyard crops are similar, the pattern 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.

Variation in welfare impacts will also depend on the land quality of the specific field a given crop is grown on. The probability of adoption of modern irrigation technologies is smaller on fields that have higher land quality because these fields may give rise to high irrigation efficiencies under traditional gravity technologies. For example, adoption is less likely to occur in citrus crops if the field 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.

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.

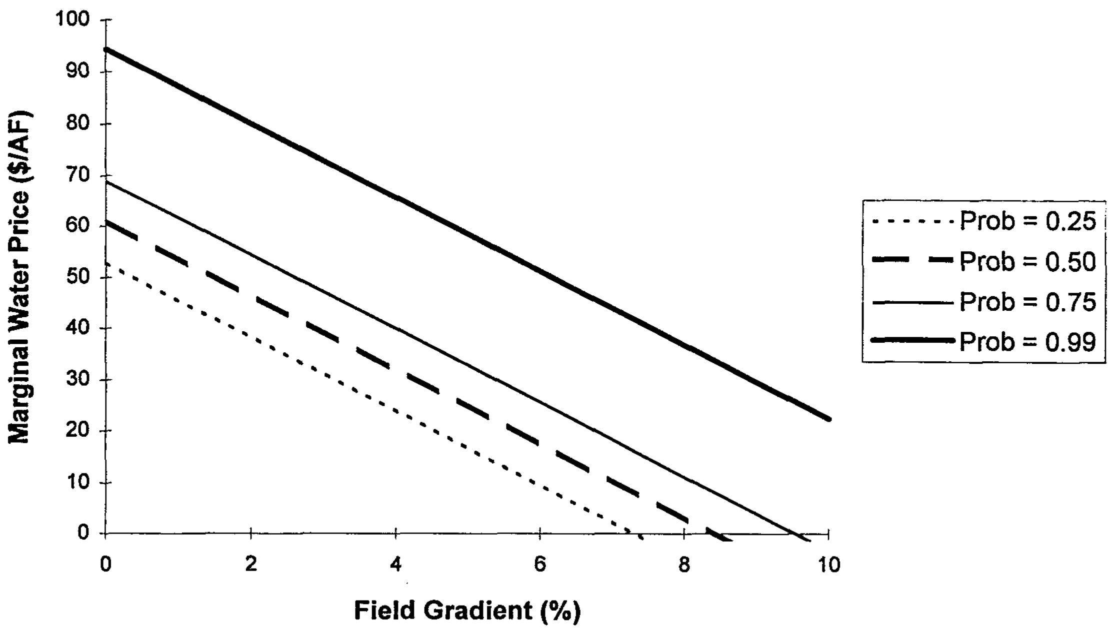

Figure 1: Iso-Probability Lines for Citrus: Field Gradient versus Water Price

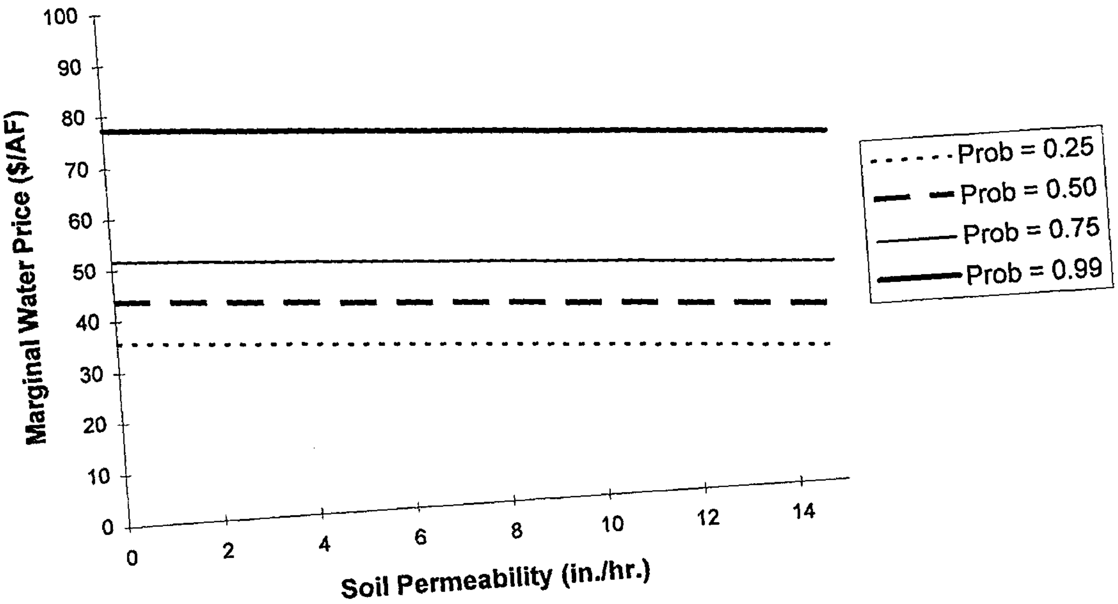

Figure 2: Iso-Probability Lines for Citrus: Soil Permeability versus Water Price

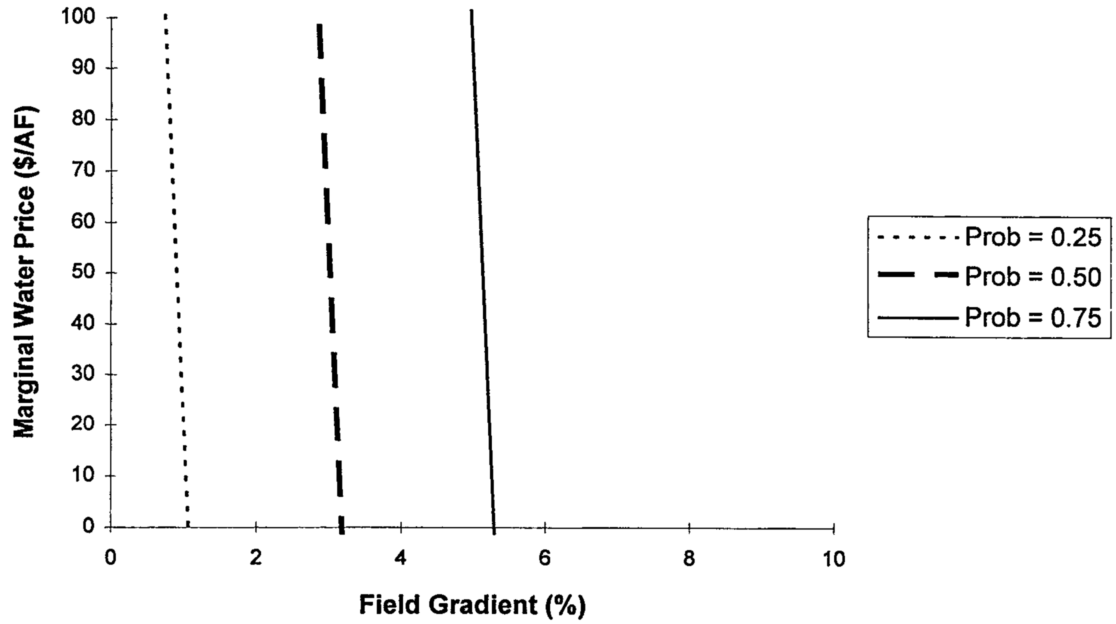

Figure 3: Iso-Probability Lines for Vines: Field Gradient versus Water Price

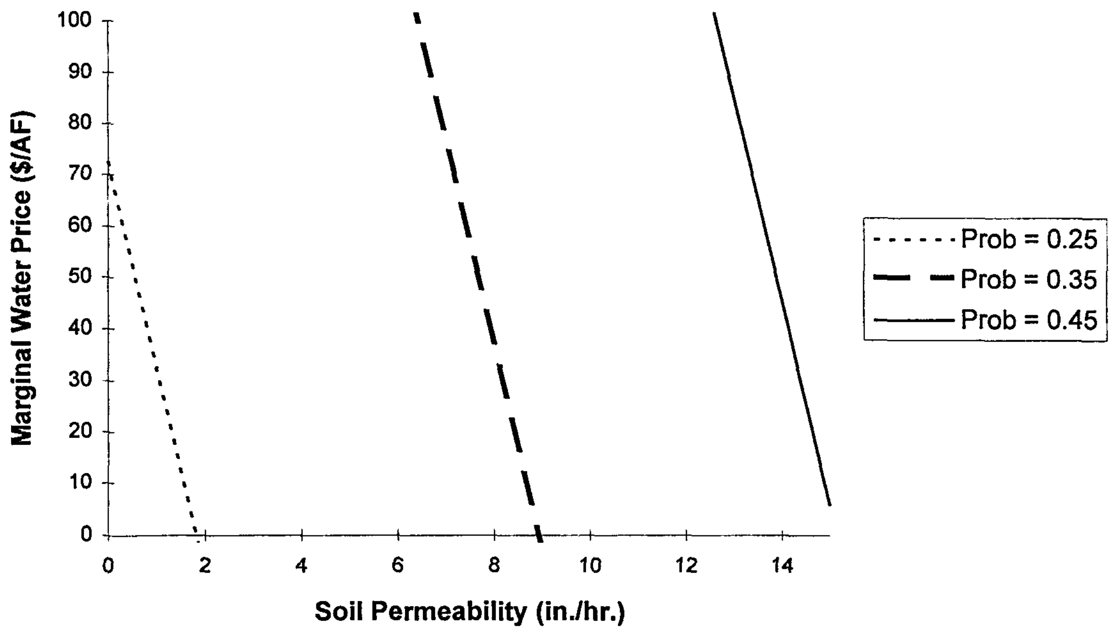

Figure 4: Iso-Probability Lines for Vines: Soil Permeability versus Water Price

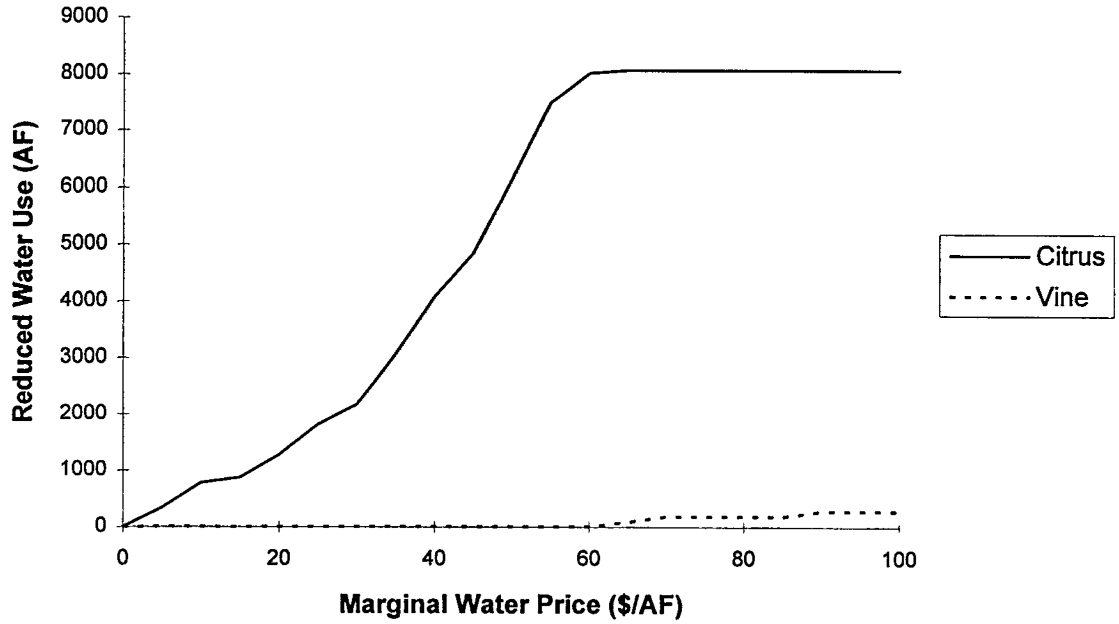

Figure 5: Reduction in Water Use for Increases in Water Price

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