Irrigation Water Rate Reform and Endogenous Technological Change

by

Eric C. Schuck, Gareth P. Green and David L. Sunding

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The authors are: assistant professor, North Dakota State University, Department of Agricultural Economics, Fargo, ND 58105; visiting professor, Seattle University, Department of Economics and Finance, Seattle, WA 98122; and Extension Economist, Department of Agricultural and Resource Economics, University of California Berkeley, CA 94720, respectively. This research was supported by a Challenge Grant from the U. S. Bureau of Reclamation in cooperation with the Natural Heritage Institute. The opinions expressed in this paper are those of the authors and do not necessarily reflect the opinions of the Arvin-Edison Water Storage District and the granting agencies.

Introduction

Traditionally, dealing with chronic and inherent irrigation water scarcity in the western United States has meant augmenting supplies through the creation of large storage and diversion projects. Increasing competition for water from urban populations, mounting costs, and rising environmental concerns are making water management policies built on physical solutions less viable, and alternatives are being sought. The use of water price as a policy tool is one such alternative receiving increased attention from western water managers. Indeed, the largest provider of irrigation water in the western United States, the Bureau of Reclamation (USBR), recently required irrigation districts in California's Central Valley to adopt conservation pricing as a Best Management Practice (USBR, 1998).

Unfortunately, irrigators adapt to changing water rates in multiple ways so the effectiveness of conservation pricing as a policy tool may be limited. Irrigators adjust water diversions, acreage allocations, and production technology to cope with rising water prices. Multi-faceted responses by irrigators have led to two major problems in the use of water price as a conservation tool. The first, as noted by Huffaker et al. (1998) in an analysis of tiered-pricing as a conservation tool, is that promoting water conservation (i.e., reducing water consumption) in one context may not promote overall improvements in water use throughout a basin or water service area depending upon return flows and irrigators' technology responses. The second problem, discussed in a survey by Michelsen et al. (1999), is that competing definitions of water conservation encourage irrigation districts to adopt water rate structures which do little to influence irrigator consumption patterns. Most of the districts surveyed by Michelsen et al. employ water rates tied to acreage served rather than water consumed, and those districts which did use volumetric pricing set rates at levels which allowed nearly all water demand to be met. Neither method necessarily promotes serious reductions in water consumption.

In the presence of varied price responses, competing conservation definitions, and the low number of irrigation districts enacting strong rate reforms, evaluating irrigation water rate reform is very complicated. This is especially true if an irrigator's primary response to a rate change is to adopt new production technology. Caswell, Lichtenberg and Zilberman (1990) and Caswell and Zilberman (1985) showed that irrigation water costs have a strong influence on a grower's irrigation technology choice and that changes in water costs promote adoption of more efficient irrigation systems. These results confirm a technical change phenomenon first noted by Hicks (1963), specifically that a change in the relative prices of inputs can induce technological change.

Unfortunately, technological change is not always easily observed. If a change in the relative price of irrigation water compels a grower to learn how to operate her enterprise differently and there are no externally observable changes in production capital, the grower has endogenously adopted a new production technology. An example of this type of change would be a grower learning how to grow new or alternative crops with which she previously had no experience. The physical attributes of the farm remain the same, but the set of crops which the grower can now produce has been expanded. Production technology has changed without external evidence.

Irrigators endogenously adopting new production technology and learning to grow alternative crops can potentially alter the relative profitability of their crop selections. Such changes can lead to rate-change responses which appear perverse. Growers switching to more profitable crops after the price change rather than before would appear to have missed an opportunity for profit. Since water rates are an input price, a rate change should not alter the relative profitability of crops and this movement would appear to be incompatible with profit maximization. However, it is compatible with a technology shift *if the irrigator could not previously select the more profitable crops*. Indeed, if a technology shift is strong enough, a rate change may even increase water demand. This paradoxical result is made all the more curious by the unobserved nature of technological change.

There have been few opportunities to evaluate if such technology shifts occur. As noted previously, few irrigation districts have enacted rate reforms strong enough to induce major adjustments in water use by irrigators. The Arvin-Edison Water Storage District (the District) in Kern County, CA is an exception. Following recommendations from researchers of this project, the District implemented a rate change for the 1995 growing season that led to both rising water use and major adjustments in crop acreage. This result was not anticipated, but may provide evidence of endogenous technological change. As a result, it is now possible to determine whether or not changes in water prices intended to reduce water consumption can induce technology adjustments that lead to paradoxical results.

Background

Significant attention has been paid to the use of water price as a conservation tool in recent years. Although the effects of block-rate pricing are unclear, much of this research has involved the use of block-rate pricing. Wichelns (1992) found that under a block-rate pricing regime water applications for some crops decreased while others increased and growers adapted their technology use. Research by Brill, Hochman and Zilberman (1998) showed that block-rate pricing was sub-optimal in comparison to water marketing systems when a system has historical water rights, while work by Huffaker, et al. (1998), showed that the use of increasing block rate prices does not necessarily lead to reductions in water consumption and may in fact promote improvements in irrigation efficiency which increase net water losses in a basin. As a whole, the use of block-rate pricing does not necessarily lead to water conservation.

Alternatives to block-rate pricing have also been explored. Tsur and Dinar (1997) in a comparison of alternative water pricing methods found that water price primarily affects cropping patterns rather than water use and that land-based fees do not lead to water use efficiency. While land-based fees did not lead to water use efficiency, Tsur and Dinar also showed that water use efficiency can be achieved through several types of water pricing and that the nature of the efficiency (i.e., short vs. long run, use vs. social) varies by water pricing method. As a result, it is by no means clear what effects alternative water pricing regimes have on water use or what pricing methods are preferred.

Determining how growers respond to alternative water rates begins with focusing on how irrigators adjust input usage to cope with changes in water price and availability. What stands out from most of the existing research is how insensitive marginal water use is to changes in water supply. Other factors, such as soil type and existing production technologies, have been shown to be more important to water use decisions (Green et al., 1996). Elasticity estimates for water typically show water as being price inelastic and not substitutable in production (Nieswiadomy, 1988; Ogg and Gollehon, 1989). Work by Sunding et al. (1997) has shown that irrigators' primary response to water scarcity and drought is fallowing rather than adjustments in water application. As a result, water analysis has shifted from marginal water application rates to longer-run issues such as analyzing the effects of changes in water price and scarcity on land allocation.

Studies emphasizing acreage allocations have confirmed that water scarcity and price typically affect irrigators at the extensive margin through land allocation rather than the intensive margin through water use rates. Moore, Gollehon, and Carey (1994) showed that while farm-level water use typically declines in water price, this does not necessarily hold true for individual crops nor is it true for crops once acreage has been allocated.

Scarcity's role in determining if water policy research should focus on land allocation or water use rates is in dictating the nature of water as a productive input. While water is often viewed as a variable input in agricultural production, research by Moore and Dinar (1995) suggests scarcity makes water a fixed, allocatable input. Such a result changes water allocation from a marginal application problem to a budgeting problem and imposes strong limitations on how growers can be modeled. In particular, as noted by Moore and Negri (1992), use of standard duality results will lead to specification errors when modeling grower behavior if water is actually a fixed, allocatable input.

While all of these studies provide valuable insight into how growers respond to changes in water scarcity and price, there are two serious points of concern which are not addressed. To start, previous work does not distinguish between groundwater and surface water supplies. Each model describes either a sole-source water supply or, when both groundwater and surface water are available, combines water supplies and assumes groundwater is the marginal source. As a result, these models do not explicitly address the issue of groundwater substitution. In many regions, imported surface water supplies were brought in specifically to reduce groundwater usage. Pricing changes which encourage growers to substitute groundwater for surface water as their primary water source may not be desirable. Isolating groundwater demand from surface water demand and assessing the effects of a change in surface water price on groundwater usage is an important policy issue.

The second issue is more fundamental and deals with the consistency of previous modeling with assumptions of profit maximization. Nearly all previous work has shown the primacy of land allocation in determining water demand and that water price changes typically lead to reallocation of acreage. Under the assumption of profit maximization, this would imply growers are moving to a crop which is more profitable after the price change than before. However, since water price is an input price, it should not influence the relative profitability of crops. A crop which is relatively more profitable *after* an input price change should have been relatively more profitable *before* the input price change.[1] Failure to move from one crop to another before the price change represents a missed opportunity for profit and suggests that growers are either behaving in a manner which is not consistent with the assumption of profit maximization or that previous models are in some way mis-specified.

A possible explanation for this apparent contradiction is technological change. If growers respond to a change in the relative price of water by altering how they manage their irrigation, they are implicitly adopting a new production technology. Since these changes in management techniques are not manifested in any physical form, they are internal to the irrigator and represent an endogenous change. This is not a new concept; work by Wichelns (1992) has shown that growers respond to changes in water price by altering how they utilize pre-existing irrigation

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[1] Richard Shumway deserves credit for this observation.

technology. As a result, external observation would show no outward changes in physical capital, but production technology is changing in response to price.

Analytical Framework

The research begins by addressing the acreage allocation and water demand decisions of an individual grower. Following Shumway (1983) and Chambers and Just (1989), the grower is modeled as a multi-output firm which is joint in production and with acreage held constant. Basically, the grower makes two decisions. The first decision is how to allocate acreage, while the second is how much water to demand from all sources given acreage. It is assumed that the grower allocates the acreage vector *l* optimally in response to all crop prices, acreage-related costs, and water prices.

Production is spread across *K* crops and is a function of acreage allocated to a crop, l_k , and effective water applied to a crop, $\delta(s_k + g_k)$. Effective water is the sum total of the grower's surface water diversions s_k , and ground water pumping, g_k weighted by irrigation efficiency, δ. Production for each of the *K* different crops is given by the function $f(l_k,\ \delta(s_k + g_k);\ \theta)$ which is concave in both acreage and effective water. Production is also a function of the grower's internal technology coefficient, θ, which represents the grower's management of existing physical capital. Adjustments in θ in response to an input price change represent endogenous technological change. If an input price change induces the grower to improve θ endogenously and the grower "learns" how to manage her resources better, grower productivity will increase as a result of an input price increase.

Grower water costs are the sum of expenditures on surface water, ground water pumping costs, and irrigation system costs. Surface water is purchased by the grower from an irrigation district at the price *r*. The grower can pump her own ground water through the function $\tilde{A}(\sum_{k}^{K} g_k ;\ \grave{e})$ which converts ground water pumping into energy consumption. The price of energy is e, so total ground water costs are $e\tilde{A}(\sum_{k}^{K} g_k ;\ \grave{e})$. Note that ground water pumping costs are a function of all ground water pumping; this is a source of jointness in production for the grower. It is assumed that the ground water pumping cost function is increasing in ground water pumping and includes drawdown effects on the aquifer. As with production, pumping is a function of the technology parameter θ. However, unlike production pumping energy is a declining function of technology so improvements in technology reduce pumping costs.

Irrigation system costs are the costs of running and maintaining an irrigation system across the grower's enterprise. These costs are a function of technology and total applied water, or $\sum_{k}^{K} (s_k + g_k)$. Since irrigation system costs depend upon total water use, this is an additional source of jointness in production for the grower. Irrigation system costs are given by the function $C(\sum_k^K (s_k + g_k); \theta)$. As with ground water pumping costs, irrigation system costs are

increasing in total water usage and decreasing in technology.

Combined with crop prices p_k and water fees tied to acreage, *h*, these functions give the grower's restricted profit function, $\pi(p, l, r, e, \theta, h, d)$. As noted by Chambers and Just (1989) and Shumway, Pope and Nash (1984), with jointness in production, individual input allocations cannot be derived via traditional duality results through Shepherd's Lemma. Instead, they are the result of solving the following maximization problem:

$$1)\quad \begin{aligned} &\pi(p, l, r, e, \theta, h, \delta) = \\ &\max_{s_k,\, g_k} \left\{ \sum_{k=1}^{K} \left[p_k f(l_k, \delta(s_k + g_k); \theta) - r s_k - h l_k \right] - e\Gamma(\sum_k^K g_k; \theta) - C(\sum_{k=1}^{K} (s_k + g_k); \theta) \right\} \end{aligned}$$

The first order conditions for equation 1) are:

$$2)\quad \frac{\partial \pi(\cdot)}{\partial s_k} = p_k \frac{\partial f(\cdot)}{\partial \delta(s_k + g_k)} \delta - r \frac{\partial C(\cdot)}{\partial \sum_{k=1}^{K} (s_k + g_k)} \leq 0$$

$$3)\quad \frac{\partial \pi(\cdot)}{\partial g_k} = p_k \frac{\partial f(\cdot)}{\partial \delta(s_k + g_k)} \delta - e \frac{\partial \Gamma(\cdot)}{\partial \sum_k^K g_k} - \frac{\partial C(\cdot)}{\partial \sum_{k=1}^{K} (s_k + g_k)} \leq 0$$

Each of these simply requires that water's marginal production value equals either the price of surface water or the marginal pumping costs of groundwater. If both water sources are used, then the price of surface water and marginal pumping cost of ground water are equal. If that does not hold, the grower will use whichever of the two water sources is cheaper. This captures the possibility of groundwater substitution due to a change in the surface water price *r*.

The solutions to equations 2) and 3) are the grower's surface and ground water demand functions. Due to the jointness introduced by the grower's pumping function and the irrigation system cost function, these demands are expressed as the farmer's total water demand and are not broken down by crop. The grower's surface and ground water demand functions are respectively:

4) $s=s\,(p, l, r, e, q, d\,)$

5) $g=g\,(p, l, r, e, q, d\,)$

The two water demands are increasing in output prices and land. Surface water declines in *r* while ground water increases, and the reverse is true for the energy price *e*. The effect on each water demand of the endogenous technology parameter θ is indeterminate. Improvements in technology improve the productivity of each unit of water. This can either reduce the amount of water used to achieve a given level of output or may promote expanded production and water demand.

To this point, the analysis has not addressed acreage beyond assuming that acreage is held constant in the restricted profit function defined in equation 1). Acreage changes are long-run adjustments to rate changes, and optimal acreage allocations are found by optimizing the solution to equation 1) over acreage. Acreage, however, differs from water demands in one critical way. Acreage is allocated at the beginning of a planting season, and most prices are not known with certainty when crops are planted. As a result, unlike water demands which are made later in the growing season and with more complete information, acreage allocation is a function of expected profits. As a result, acreage allocations are found by solving the following problem:

6) $$ð(\,p,\ r,\ e,\ è,\ h,\ ä) \;=\; \max_{l_k}\ E\left\{ð(\,p,\ l,\ r,\ e,\ è,\ h,\ ä)\right\}$$

where E denotes the expectations operator. The solution to equation 6) is:

7) $$l_k^* \;=\; l_k(\,p,\ r,\ e,\ è,\ h,\ ä)$$

Acreage is increasing in output prices, and decreasing in surface water price, energy price, and acreage related water fees. As with the two water demands, the effects of technology are indeterminate.

The combination of alternative water sources and technological change greatly complicates the analysis of a rate change. The grower's applied water demand, or *AW*, is the sum total of her ground and surface water demand for all crops, or:

8) $$AW \;=\; \{\,s(\cdot) \;+\; g(\cdot)\,\}$$

Differentiating equation 8) with respect to surface water *r*, gives:

9) $$\frac{\partial AW}{\partial r} \;=\; \left\{\frac{\partial g(\cdot)}{\partial r} + \frac{\partial s(\cdot)}{\partial r} + \left[\frac{\partial g(\cdot)}{\partial \sum_k l_k} + \frac{\partial s(\cdot)}{\partial \sum_k l_k}\right]\left(\frac{\partial \sum_k l_k(\cdot)}{\partial r} + \frac{\partial \sum_k l_k(\cdot)}{\partial è}\,\frac{\partial è}{\partial r}\right) + \left[\frac{\partial g(\cdot)}{\partial è} + \frac{\partial s(\cdot)}{\partial è}\right]\frac{\partial è}{\partial r}\right\}$$

The grower's response to the price change can be broken down into three effects. The first is a direct effect on surface and ground water demands, given by $\frac{\partial g(\cdot)}{\partial r} + \frac{\partial s(\cdot)}{\partial r}$. Surface water use is declining in *r* while ground water is increasing in *r*, so for a price increase the grower reduces surface water but replaces some of it with ground water.

The next effect relates to acreage and is given by $\left[\frac{\partial g(\cdot)}{\partial \sum_k l_k} + \frac{\partial s(\cdot)}{\partial \sum_k l_k}\right]\frac{\partial \sum_k l_k(\cdot)}{\partial r}$. This effect is where the grower adjusts acreage in response to a rate change. Assuming that acreage and water are complimentary in production, this effect should be negative as the grower reduces acreage.

The last effect is the most difficult to evaluate, and is related to the technology parameter θ. Measured by $\left\{\left[\frac{\partial g(\cdot)}{\partial \sum_k l_k} + \frac{\partial s(\cdot)}{\partial \sum_k l_k}\right]\frac{\partial \sum_k l_k(\cdot)}{\partial \grave{e}} + \left[\frac{\partial g(\cdot)}{\partial \grave{e}} + \frac{\partial s(\cdot)}{\partial \grave{e}}\right]\right\}\frac{\partial \grave{e}}{\partial r}$, the influence of an improvement in technology on applied water is indeterminate. While technology is enhanced in response to a price increase and $\frac{\partial \grave{e}}{\partial r}$ is therefore positive, the influence of a technology improvement on each of the input demands is difficult to determine a priori. An improvement in technology may reduce the demand for each input by improving production efficiency, or it may make each input more productive. The latter can potentially increase demand for the input, even as the price increases. Additionally, the results of a technological improvement may not affect all inputs equally. Since applied water is a function of both water sources and each of the two water sources are functions of acreage, different responses between inputs leads to great uncertainty about the overall effect of a rate increase. The end result is that the combination of water substitutability and technological change makes it impossible to determine if applied water demand is rising or falling in response to a rate increase. Empirical determination is a necessity.

Empirical Model and Estimates

The Arvin-Edison Water Storage District (the District) in Kern County, CA manages a conjunctive use system with highly variable water supplies. Since first receiving surface water deliveries in 1966, the District has seen supplies range from a low of 36,000 acre-feet to a high of 376,000 acre-feet. During droughts, which the District defines as any water year where surface water supply is less than surface water demand, the District operates groundwater pumps to supply water to growers who cannot access groundwater and encourages growers with access to groundwater to use these resources rather than scarce surface water supplies. The District experiences these conditions to varying degrees of severity 45% of the time.

As part of its drought management strategies and in response to the recommendations of researchers of this project, the Arvin Edison Water Storage District (the District) adopted a new rate structure in 1995. The rate change moved growers from a contracted quantity purchased at the beginning of a growing season to a price-based system. The original system often resulted in growers purchasing more water than was necessary and was perceived as promoting excessive pre-irrigation at the end of each water year as growers tried to consume water they had already purchased. The new system allows growers to purchase water as it is needed and was intended to improve marginal water use efficiency by either reducing water deliveries or improving the profitability of applied water. The effects of the rate change are not obvious. In every year since the rate change, the District has seen water use rise while cropping patterns have oscillated between a variety of different crops. Existing irrigation technologies do not appear to have changed in response to the rate change. As a result, it is unclear if the rate change had its originally intended effect of promoting water conservation. This research analyzes how growers responded to the changes in water rates and if those responses led to significant crop switching or reductions in water use. In particular, the research determines if there is evidence of endogenous technology shifts in response to the water rate change.

Using District water demand and acreage data from 1982-1998, the effects of the 1995 rate change are evaluated by developing an input demand system for the District and estimating water demand and acreage allocation. District surface water demand and acreage allocations are taken from District records, while ground water demand comes from the engineering firm of Bookman-Edmonston. The model assumes a restricted quadratic production technology for output and a quadratic cost function for ground water and irrigation water costs. To preserve homogeneity, all prices are expressed relative to District surface water prices. The restricted quadratic specification has the advantage of being both a flexible functional form and linear in parameters. For the empirical analysis, the *k* crops are represented by the following categories:

alfalfa, cotton, field, grain, pasture, potatoes, truck, vineyards, deciduous, and citrus.[2]

Two types of equations are estimated econometrically. The first type is the two district-level surface and ground water demands. Each water demand is a function of surface water price, the average cost of groundwater[3], and acreage allocations.[4] To determine if a change in the relative prices of the two water sources induced an endogenous technological change, a technology trend variable is weighted by the ratio of surface water price to average ground water costs and included in both water demands. Drought and rate change dummy variables are also included to determine if either drought conditions or the 1995 rate change led to structural change in the District.

Acreage allocations are the second type of equation estimated. For these equations, crops in the District were divided into two general categories: annuals and perennials. Alfalfa, field, grains, pasture, potatoes and truck were the annual crops, while citrus, deciduous, and vineyards were the perennial crops. The distinction was made to capture the difference in planting flexibility between the two different crop categories. Annual crops were modeled as a function of all crop prices, average ground water costs, and surface water price[5]. Acreage-related charges were

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[2] Crop prices are the lagged weighted average prices for these crops as reported by the Kern County Agricultural Commission in their *Annual Report*. These crop categories reflect the standard classifications used by the District.

[3] The average cost of ground water is a function of the observed aquifer level and the energy rates charged farmers by Pacific Gas and Electric under their Agricultural Rate Schedule 5b.

[4] Crop prices were also initially used, but were excessively collinear with acreage.

[5] This specification assumes jointness in production due to jointness in water costs. Jointness due to a fixed, allocatable acreage constraint was explored but rejected.

dropped because the District assesses these as a fixed levy which does not influence marginal acreage decisions. As with the water demand equations, a technology trend interaction variable, rate change policy dummy, and drought dummy were also included.

Perennial crops were modeled in a slightly different manner. Since adjustments in perennial crops are not done easily, perennial acreage was modeled as a function of lagged acreage, crop prices, average ground water costs, surface water price, and the three policy analysis variables.   As with the two water demand equations, a technology trend variable weighted by the ratio of surface water price to ground water costs is included to determine if a change in the relative prices of water induced a technological change in acreage allocations.

Estimation is carried out in GAMS using single equation Generalized Maximum Entropy (GME) as outlined by Mittelhammer and Cardell (1997). GME is employed due to its relatively better small sample properties and greater efficiency with collinear data sets in comparison to least squares estimators. While ordinarily a systems-type estimator would be utilized to account for simultaneities between acreage allocation and water demand, it should be noted that the land allocation and water demand equations are diagonally recursive (since land appears as an explicit argument in the water equations but not vice versa) so single equation estimation is valid (Kmenta, p. 586; Greene, pp. 596-97).

Results and Conclusions

The results from the econometric analysis are contained in Tables 1) through 3). Table 1) contains the parameter estimates and t-statistics for the two water demand equations. Annual acreage results are contained in Table 2), and perennial acreage results are in Table 3).

The two water demand equations performed well, particularly given the degree of collinearity present in the data. The first interesting issue to come out of the water demand models is the singular importance of acreage levels in determining water demand. For surface water demands, acreage is significant for all of the 10 crop types and acreage is significant for 7 of the 10 crop types for ground water. While output prices were initially dropped from the water demand equations to cope with collinearity problems, excluding these variables did not significantly alter the results. This suggests that in the presence of two water supplies and fixed acreage, water is strictly essential in production relative to acreage allocations and water demand reduces to a cost minimization problem between the two water sources. As a result, when alternate water sources are available, crop prices influence water demand through acreage allocations and not through the value of the marginal product of water.

The price of surface water relative to ground water costs is directly significant for surface water but not for ground water demand, and is significant through the technology trend variable only for surface water. While this may seem counter-intuitive, it matches ground water's role as a residual source of water supply. Surface water price influences ground water primarily through the decision to switch water sources, and as a result may not directly influence marginal ground water demand decisions.

What is most critical between these two water demands, however, is the significance and negative sign of the technology trend/relative water price variable in the surface water demand equation. Compared to the relative price variable alone, this variable is much larger in its impacts. This suggests that suggests that in the short run demand for surface water is relatively inelastic and strictly essential in production with respect to acreage, but that as time passes irrigators become much more sensitive to changes in the relative price of water and adjust water consumption downward. This outcome supports the hypothesis of endogenous technological change since the long-run trend related to relative changes in water prices is to reduce water demand while the immediate response is either small or indistinguishable from zero. The drought and rate change policy dummy variables were not significant for either water demand.

The influence of surface water price on annual acreage allotments is difficult to assess. Surface water price appears relative to both output prices and ground water costs. For each of the seven annual crops, the parameters tied to own-output price and some substitute output crop prices relative to surface water price are significant. The significance of many of the cross-price parameter supports the assumption of jointness in production in the model specification.

The parameters associated to relative water prices and the technology trend/relative water price variable, however, are insignificant for all of the annual crops. This suggests that for each of the annual crops, the ability to substitute between crops on an annual basis provides adequate flexibility for coping with changes in relative water prices. Additionally, for annual crops relative changes between output prices and water prices exert more of an influence on acreage levels than changes in relative water costs alone. This also matches the conclusion from the water demand equations that water demand is driven primarily by acreage, but acreage levels are driven by output prices.

While annual crops did not respond to relative changes between surface water price and ground water costs either in the short or long run, perennial crops were sensitive to both of these changes. The short-run parameters tied to the effects of relative changes in output prices and water prices were significant for all of the three perennial crops. More importantly, for all three of the crops the effects of the technology trend/relative water costs parameter was positive and significant. These crops are among the most important crops in the District and account for nearly 50% of the District's irrigated acreage. A positive long-run technology response in acreage to changes in relative water prices for these crops can potentially explain the unusual increase in water demand the District observed following the 1995 rate change. This response suggests growers are expanding the acreage of these two crops in response to long-run increases in the relative cost of surface water.

This outcome has significant implications. Since the effect of the rate change is to reduce annual acreage but to increase perennial acreage, irrigators are adopting perennial crops as a means of moving acreage out of less profitable annual crops. Cultivation of perennial crops tends to be very different from annual crops. Perennial crops require a longer commitment of resources to a crop. Even if all of the physical attributes of an enterprise remain the same, the adoption of perennial crops in lieu of annual crops represents movement into an alternative production technology. If the District's rate change reduced the hurdle associated with moving from annual to perennial crops, the District's 1995 rate change may have inadvertently promoted investment in perennial crops. Water costs represent a much lower fraction of total costs for perennial crops than for annual crops, so while movement into perennial crops may lead to increases in water consumption it can also reduce the effects of rising water rates. Irrigators appear to be adopting perennial crops as a means of investing their way out of the effects of the rate change, a result consistent with the hypothesis of technological change previously put forward.

Further support for this hypothesis can be found in Tables 4) and 5). Table 4) follows equation 11) and decomposes the marginal effects of a change in the surface water price r on applied water demand. The short-run effects of the rate change are small and largely countervailing as ground water is substituted for surface water, but the longer run effects conveyed through acreage and technology changes are much more pronounced and generally negative. The sum of all effects is negative, which is consistent with profit maximization and concave production technologies.

When the marginal effects of a rate change on perennial acreage are isolated, however, the picture becomes slightly different. As shown in Table 5), the net acreage effects of a rate change are to *increase* water demand from perennial acreage. Since these crops account for almost half of all of the cultivated acreage in the District, this positive effect may explain the acreage adjustments observed by the District following the 1995 rate change. Unfortunately, while it is possible to isolate the acreage effects of the rate change, the two water demand equations cannot be segregated by crop. As a result, it is not possible to isolate how the rate-change influenced water demand for perennial crops. Given the importance of perennial crops in the District, their acreage effects may be dominating any water use reductions implied by the two District-wide water equations. If that is the case, annual crops may be extremely sensitive to water rate variations, while perennial crops are not. This is an issue which should be explored further.

Traditionally water demand analysis does not differentiate between water sources. This study explicitly addresses the role water source substitutability plays in water demand and determines how changes in surface water rates affect both acreage allocations and water demands. Results suggest that growers facing a rate change will respond through adjustments in both marginal water applications and acreage adjustments. Much of the acreage response appears to be movement from annual crops to perennial crops, a result which is indicative of induced-technological change. Unfortunately, while the 1995 rate change in the Arvin Edison Water Storage District appears to have encouraged adoption of perennial crops, the empirical results do not fully answer all questions stemming from that policy change. In particular, econometric results suggest that marginal water usage should decline when in fact it rose. While this may be explained by the high percentage of the District's acreage dedicated to perennial crops, available data cannot adequately address this issue and further research is needed.

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Table 1: Coefficients for Water Demand

	Surface Water	Ground Water
Constant	20.69	5.53
t-value	0.71	0.06
Alfalfa	4.89	3.66
t-value	5.98****	1.40*
Cotton	3.38	1.67
t-value	41.71****	6.42****
Field	5.28	4.35
t-value	1.95***	0.51
Grains	4.76	3.33
t-value	12.05****	2.63***
Pasture	5.32	4.45
t-value	1.42*	0.37
Potatoes	3.27	1.44
t-value	14.3****	1.97**
Truck	3.54	1.71
t-value	19.54****	2.94****
Citrus	4.67	2.25
t-value	10.16****	1.53*
Deciduous	4	1.98
t-value	1.81**	0.28
Vineyards	2.62	1.14
t-value	9.35****	1.27*
r/v	-26.52	17.97
t-value	-3.34****	0.71
(r/v)*technology	-21.82	2.15
t-value	-27.56****	0.85
Rate Change	0.53	-17.68
t-value	0.08	-0.85
Drought	-2.36	-8.79
t-value	-1.78**	-2.06***

NOTE: *r* is District surface water price; *v* is expected ground water cost given aquifer level and PG&E energy rates.

Rate Change is dummy variable for 1995 rate change; Drought is dummy variable for 1991 drought.

LEGEND:
**** Significant at 0.01 level
*** Significant at 0.05 level
** Significant at 0.1 level
* Significant at 0.2 level

Table 2: Coefficients for Annual Acreage Allocations

	Alfalfa	Cotton	Field	Grain	Pasture	Potatoes	Truck
Constant	4.90	5.15	4.90	4.81	4.67	4.93	4.89
t-value	2.01***	1.72**	2.21***	2.17***	1.68**	1.91**	2.29***
Alfalfa Price	-9.42	9.19	8.64	8.61	7.99	8.78	8.68
t-value	-14.75****	11.75****	14.91****	14.86****	11.00****	13.00****	15.54****
Cotton Price	0.01	-0.23	0.15	0.00	0.00	0.07	0.07
t-value	0.16	-2.97****	2.61****	0.00	0.00	1.05	1.27
Field Price	8.91	10.41	-10.62	8.65	8.10	9.19	9.28
t-value	2.10***	2.00***	-2.75****	2.24***	1.68**	2.05***	2.50***
Grain Price	9.80	10.03	9.69	-10.48	9.30	9.67	9.67
t-value	2.00***	1.68**	2.18***	-2.36***	1.67**	1.87**	2.26***
Pasture Price	9.59	9.97	9.82	9.61	-10.46	9.68	9.79
t-value	2.94****	2.50***	3.32****	3.25****	-2.82****	2.81****	3.44****
Potato Price	9.76	10.08	9.87	9.73	9.62	-10.16	9.86
t-value	1.74**	1.47*	1.94**	1.91**	1.51*	-1.71**	2.01***
Truck Price	9.47	9.96	9.76	9.47	9.35	9.59	-10.28
t-value	2.96****	2.54***	3.36****	3.26****	2.57***	2.84****	-3.68****
r/v	-27.45	-22.76	-26.44	-28.38	-30.28	-26.47	-26.74
t-value	-5.58****	-3.78****	-5.92****	-6.35****	-5.41****	-5.09****	-6.21****
(r/v)*technology	-0.27	0.00	-0.07	-0.22	-0.26	-0.17	-0.10
t-value	-0.57	0.00	-0.16	-0.51	-0.48	-0.34	-0.24
Rate Change	-0.46	-0.21	-0.11	-0.37	-0.37	-0.38	-0.17
t-value	-0.25	-0.09	-0.07	-0.22	-0.18	-0.20	-0.11
Drought	-0.18	0.21	-0.08	-0.15	-0.19	-0.06	-0.10
t-value	-0.17	0.16	-0.08	-0.15	-0.15	-0.05	-0.11

Note: Prices refer to r/p_k, so Alfalfa Price is $r/p_{alfalfa}$.

LEGEND:
**** Significant at 0.01 level
*** Significant at 0.05 level
** Significant at 0.1 level
* Significant at 0.2 level

Table 3: Coefficients for Perennial Acreage Allocations

	Citrus	Deciduous	Vineyard
Constant	5.10	5.16	5.33
t-value	10.06****	1.95**	2.14***
Own Price	-4.98	-4.99	-4.96
t-value	-1.59*	-0.46	-0.31
Lagged Acreage	0.04	0.07	0.34
t-value	0.46	0.31	4.39
r/v	-2.49	-2.48	-2.47
t-value	-3.02****	-2.61****	-0.84
(r/v)*technology	0.64	0.56	1.06
t-value	4.89****	6.71****	6.66****
Rate Change	0.03	0.01	0.03
t-value	0.06	0.02	0.02
Drought	0.04	0.03	0.06
t-value	0.27	0.14	0.13

Note: Own Price refers to r/p_k, so Own Price for Citrus is Price is r/p_{citrus} .

LEGEND:
**** Significant at 0.01 level
*** Significant at 0.05 level
** Significant at 0.1 level
* Significant at 0.2 level

Table 4: Sample Marginal Effects of a Surface Water Rate Change

Year	1994	1995	1996	1997	1998
$\frac{\partial s(\cdot)}{\partial r}$	-0.29	-0.30	-0.30	-0.30	-0.30
$\frac{\partial g(\cdot)}{\partial r}$	0.20	0.20	0.20	0.21	0.21
$\sum_k \frac{\partial s(\cdot)}{\partial l_k} \frac{l_k(\cdot)}{\partial r}$	-0.93	-1.06	-1.55	-1.78	-1.59
$\sum_k \frac{\partial g(\cdot)}{\partial l_k} \frac{l_k(\cdot)}{\partial r}$	-0.72	-0.83	-1.17	-1.29	-1.12
$\frac{\partial s(\cdot)}{\partial \grave{e}} \frac{\partial \grave{e}}{\partial r}$	-3.13	-3.43	-3.71	-3.99	-4.24
$\frac{\partial g(\cdot)}{\partial \grave{e}} \frac{\partial \grave{e}}{\partial r}$	0.31	0.34	0.37	0.39	0.42
$\sum_k \left\| \frac{\partial s(\cdot)}{\partial l_k} \frac{\partial l_k(\cdot)}{\partial \grave{e}} \frac{\partial \grave{e}}{\partial r} \right\|$	0.43	0.47	0.51	0.54	0.58
$\sum_k \left\| \frac{\partial g(\cdot)}{\partial l_k} \frac{\partial l_k(\cdot)}{\partial \grave{e}} \frac{\partial \grave{e}}{\partial r} \right\|$	0.02	0.02	0.03	0.03	0.03
$\frac{\partial AW}{\partial r}$	-4.12	-4.58	-5.63	-6.19	-6.03

Table 5: Marginal Acreage Effects for Perennial Crops

Year	1994	1995	1996	1997	1998
$\sum_p \frac{\partial s(\cdot)}{\partial l_p}\frac{l_p(\cdot)}{\partial r}$	-0.37	-0.37	-0.38	-0.38	-0.38
$\sum_p \frac{\partial g(\cdot)}{\partial l_p}\frac{l_p(\cdot)}{\partial r}$	-0.18	-0.18	-0.18	-0.18	-0.18
$\sum_p \left\| \frac{\partial s(\cdot)}{\partial l_p}\frac{\partial l_p(\cdot)}{\partial \theta}\frac{\partial \theta}{\partial r} \right\|$	1.15	1.26	1.36	1.47	1.56
$\sum_p \left\| \frac{\partial g(\cdot)}{\partial l_p}\frac{\partial l_p(\cdot)}{\partial \theta}\frac{\partial \theta}{\partial r} \right\|$	0.54	0.59	0.64	0.69	0.73
$\sum_p \frac{\partial AW}{\partial l_p}\frac{\partial l_p}{\partial r}$	1.14	1.30	1.45	1.59	1.73