Agricultural Water Demand and the Gains from Precision Irrigation Technology

by

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This paper estimates the parameters of agricultural water demand. Estimation results indicate that water use is responsive to changes in the price of water. The estimation results also find that the water savings from investment in precision irrigation technology vary widely by crop, but can be as high as 50 percent.

Allocation of scarce freshwater resources is an issue of great importance in dry regions of the world. Economists and other observers have argued that policies to improve the efficiency of water allocation can help alleviate conflicts among competing users and minimize water's role as a limit to growth. Efficiency-enhancing water management strategies can also help reconcile supply and demand imbalances without resorting to costly and environmentally damaging dams and other supply augmentation measures.

Water Use and Agriculture

Agriculture is the dominant user of water in the western United States and most other arid regions of the planet. Lacking adequate precipitation during the growing season, agriculture in these areas is dependent on large-scale diversion of surface water and groundwater pumping. In California, for example, even though large urban areas like Los Angeles, San Francisco and San Diego are almost entirely reliant on surface water diversion, agriculture in the state uses nearly 80 percent of developed surface water resources. In fact, considerably more water is used to grow hay in the state than is consumed by all the households and businesses in Los Angeles and San Francisco combined.

Using a unique panel data set from California's San Joaquin Valley, the results in this paper shed light on the short- and long-run responsiveness of farm water demand to changes in the marginal price of water.

One benefit of the estimation approach we employ is that it permits direct estimation of water conserved by the adoption of conservation technology. Our results show that there can be substantial savings from investment in precision irrigation technology, with reductions in water use per acre exceeding 40 percent in a few instances.

Due to the interest in using price reforms to manage water demand, a main objective of our analysis is to measure the responsiveness of farm water use to changes in the price of water. Our results allow us to distinguish between the changes in short- and long-run demand. Choices of outputs and production technologies are assumed to adjust over time, and thus a water price shock will have long-run effects through its influence on output and technology choice that will be distinct from the short-run effects that incorporate mainly management changes.

Data

Most of the data used in the estimation comes from Arvin Edison Water and Storage District (AEWSD). The data set includes an eight-year panel (1994-2001) in AEWSD. Annual data are collected at the field level on both the crop and irrigation system. Water price and delivery data are also provided by AEWSD. Combining records of technology and output choice by field with water delivery data, it is possible to piece together a fairly complete picture of water-use decisions at the micro level. Also important is the fact that in 1995, the District enacted a major water rate reform. By comparing water use before and after the rate reform, we can capture the effects of the price change, controlling for factors such as environmental conditions and changes in output prices.

Table 1 gives a summary of the land allocation over the sample period. The main citrus crop in the region is oranges; deciduous crops include mostly almonds, along with some peaches and apples. Truck crops include potatoes, carrots and onions, while field crops include cotton and some hay. Interestingly, perennial crop acreage has increased in recent years despite overarching concerns about agricultural water supply reliability. In 1994, perennial crops were planted on 49 percent of total acreage. By 1998, this had increased to 63 percent of total acreage.

Water Use and Capital Investment

In our analysis we explain water use at a particular location as a function of output and technology choices, relative prices and other factors such as environmental characteristics. Our estimation strategy assumes that the durability of physical capital fixes the input/output

Table 1. Land Allocation Over Time by Crop and Technology Type*

Crop	Irrigation	1994	1995	1996	1997	1998	1999	2000	2001
Citrus	*Drip*	16.9	16.8	16.4	20.9	22.0	22.4	22.0	22.3
	Gravity	1.9	2.0	2.2	2.3	2.4	0.9	1.4	1.3
	Sprinkler	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
Grape	*Drip*	9.3	9.3	9.4	12.0	12.8	18.5	15.6	15.8
	Gravity	10.1	11.6	10.9	12.6	12.4	8.0	9.6	10.2
	Sprinkler	0.0	0.0	0.0	0.2	0.2	0.0	0.4	0.3
Deciduous	*Drip*	3.8	3.8	4.5	6.8	7.4	5.3	5.6	6.0
	Gravity	2.9	2.6	3.6	3.5	3.8	4.1	4.2	4.6
	Sprinkler	4.5	4.6	1.9	2.6	2.1	3.1	1.8	1.9
Truck	*Drip*	0.6	0.5	0.2	1.0	0.3	0.7	1.6	0.8
	Gravity	4.0	3.2	0.0	3.7	3.5	3.8	4.2	2.3
	Sprinkler	27.3	24.8	29.7	12.4	16.6	17.0	16.0	16.7
Field	*Drip*	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	Gravity	0.5	1.1	0.0	0.4	0.1	0.0	0.2	0.0
	Sprinkler	18.3	19.7	21.3	21.5	16.2	16.3	17.4	17.6
All Perennial Crops	*Drip*	30.0	29.9	30.3	39.7	42.2	46.2	43.2	44.2
	Gravity	14.9	16.2	16.7	18.4	18.6	12.9	15.2	16.2
	Sprinkler	4.5	4.6	1.9	2.9	2.4	3.1	2.2	2.2
All Annual Crops	*Drip*	0.6	0.6	0.2	1.0	0.3	0.7	1.6	0.8
	Gravity	4.4	4.2	0.0	4.1	3.6	3.8	4.4	2.3
	Sprinkler	45.5	44.5	51.0	33.9	32.8	33.3	33.4	34.3

** Land allocations are expressed in percentages, with the sum of citrus, grape, deciduous, truck and field crops in each year equal to 100.*

ratio in the short run, but that the choice of technology will adjust over time to changes in the relative prices of inputs and outputs. The choice of crop can also be viewed as a particular type of capital investment, as all crops require a significant investment in specialized farm equipment and human capital, while perennial crops also require capital investment in plant stock.

Water Savings from Precision Technology

An interesting and useful result of this analysis is that it allows measurement of the water savings resulting from investment in precision irrigation technology. To our knowledge, this is the first time such a benefit from investment in agricultural water conservation technology has been demonstrated and measured under field conditions. By comparing the coefficients of the same crop under different irrigation technologies in the water demand estimation, we can estimate the reduction in water application per acre from a change in technology. This analysis is done under the assumption that all other factors, such as slope, soil permeability and climate variables, are held constant. The results are presented in Table 2. With the exception of the comparison of water use by deciduous crops in gravity and in sprinkler irrigation, all of the coefficient pairs are found to be significantly different. In some cases, adoption of precision technology can cut water use per acre close to half.

Another important finding is that precision technology appears to result in different amounts of conservation when used on different crops. For example, drip irrigation uses only half the water of gravity irrigation with citrus crops. Therefore, the gain in moving from gravity to drip in citrus is very high. In grapes, drip irrigation also uses less water then gravity, but the difference is much smaller (a 30.2 percent reduction instead of a 46.4 percent reduction). The differential gains of the switch to efficient technology make sense from an agronomic or physical point of view as well. With citrus crops, the trees are widely spaced, leaving a lot of land between the trees where water is not used by the plant. Applying water directly to the root zone, as is the case with drip irrigation, will accordingly result in more water savings. Grapevines are planted much closer to each other, resulting in less wasted water from gravity-applied irrigation water.

Responses to Changes in Water Price

One benefit of our estimation approach is that the response to changes in water price can be decomposed into direct and indirect effects, where the indirect effects include changes in capital investment and land allocation.

We find that the indirect effect is unambiguously negative; implying that a change in the price of water induces water-conserving changes in crop and technology choices. It should also be noted that the indirect effects of water price changes are smaller than the direct effects. This pattern is explained by the fact that, while the price of water has been shown to be a significant determinant of adoption of conservation technology in agriculture, it is by no means the only determinant. Other factors such as weed control, a desire to save on labor costs, or a need to apply fertilizers precisely through the irrigation system can all spur investment in precision irrigation systems.

Our results show that agricultural water demand is somewhat more responsive to changes in the price of water than indicated by previous studies. Accordingly, one implication is that water rate changes can have a larger effect on water allocation than previously assumed. It is also worth noting that our panel only includes seven years of data after the major rate change. Given the durability of capital investments in irrigation systems, which can have a useful life of ten years or more, and plant stock, which can last up to forty years for some trees and vines, we would expect indirect effects to be larger when measured over a longer time period.

Some simple calculations help to illustrate the relative magnitudes of the direct and indirect effects. Table 3 summarizes our results, and shows how an increase in the marginal price of water reduces agricultural water use. For example, an increase of ten percent in the marginal price of water of $5.73 per acre-foot will reduce water use by 44.2 acre-feet per section, or 0.126 acre-feet per acre. Of this reduction, 83 percent is due to better management, and 17 percent is due to changes in crop or irrigation technology.

Table 3. Effect of Changes in Marginal Water Price on Average Water Use

Percent Increase in Water Price	Water Price**	Avg. Water Use*	Direct Reduction	Indirect Reduction
		-----------Per Acre-------------		
0	57.3	3.034		
10	63.0	2.908	0.105	0.021
15	65.9	2.845	0.157	0.032
20	68.8	2.782	0.209	0.042
25	71.6	2.719	0.262	0.053
30	74.5	2.656	0.314	0.064

** Water use is measured in acre-feet*

*** Water price is the marginal cost per acre-foot in dollars*

Table 2. Differences in Water Use Between Irrigation Technologies by Crop

	Irrigation Technologies Compared *		Percent Reduction in Water Use Coefficient **	
Type of Crop	Drip & Gravity	Gravity & Sprinkler	Drip & Gravity	Gravity & Sprinkler
Citrus	YES	n/a	46.4	n/a
Grape	YES	n/a	30.2	n/a
Deciduous	YES	NO	43.7	0.0
Truck	n/a	YES	n/a	41.9

**** These columns answer the question "Is water use significantly different under the two compared irrigation technologies in the type of crop listed?" The tests that are not applicable (n/a) contain crop and technology combinations that are not observed in our data set.***

***** These columns show the percentage reduction in estimated water use from switching from gravity irrigation to a more efficient technology.***

Conclusions

Agriculture is the most important user of water in the western United States and in most arid regions of the world. As a result of rapid population growth and increasing concern about the environmental effects of surface water diversions, agricultural interests are under increasing pressure to conserve water. Our results indicate that an increase in the marginal price of agricultural water reduces demand for water. Of this reduction, the indirect effects of water price on output and technology choices account for roughly 17 percent of the total. This finding suggests that more active management has a large influence on water use. With larger price changes, indirect effects may be a larger fraction of the total.

Another important finding concerns the conservation benefits of adoption of precision irrigation technology. Comparing coefficients in the demand equation, the savings from switching from, say, gravity irrigation to drip is measured directly. For some crops, the water savings from investment in modern technology is large—close to 50 percent per acre. For others, the savings are not nearly as great. These findings provide a window on the performance of programs designed to stimulate investment in modern irrigation technologies and suggest that expectations of water savings should be conditioned on land allocation among crops.

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