

# WATER CONSERVATION TECHNOLOGY: THE ADOPTION RESPONSE TO INCENTIVES

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## ABSTRACT

Water use in agriculture depends heavily on the adoption of efficient irrigation technologies. It is therefore essential to provide incentives for the adoption of these technologies in arid regions. In real world applications, this task is complicated by missing markets and restrictions on policy tools. Often, property rights are not well established for water and regulatory agencies do not have the mandate to set appropriate prices or fees. In addition, precision conservation technologies are information intensive. This feature of production reduces efficiency through the market failures associated with the public good properties of information. However, it also provides regulators with a new, surprisingly successful policy tool, the provision of information. This paper uses the public good properties of information and the nature of precision irrigation technologies to explain the unanticipated success of information based program in California and its relationship to other incentives in encouraging the adoption of conservation irrigation technologies.

## INTRODUCTION

In arid regions such as California agricultural, environmental, and municipal users compete fiercely for scarce water resources. Approximately 80 percent of California's water is supplied to a 20 billion dollar irrigated agricultural industry (Parker, 1997). If urban landscaping, golf courses, and parks are included, the share of water applied by irrigation is even greater, as is the commercial value of its use. Since water consumption depends heavily on the irrigation technology used, the adoption of water efficient precision irrigation systems is critical (Khanna & Zilberman, 1997).

In the most naive analysis, the incentives necessary to encourage the appropriate adoption levels are straightforward: Ensure that water users pay a price for water that is equal to its true shadow value. Not surprisingly, the practical situation in California is too complicated for the direct application of this principal. Water supply and regulatory agencies are limited in what fees they can charge. Uncertainty in water rights

hinders efficient markets, as do regulations restricting trades.

In addition, conservation oriented irrigation technologies can be highly information intensive, which means that information related issues must be understood for appropriate management. In fact, adoption incentives based on public weather information provision in California have demonstrated an unanticipated level of success. This paper discusses the factors behind the successes and weaknesses of information programs and how they are linked to water pricing in providing incentives for adoption of conservation irrigation technologies.

## MARKETS AND FAILURES

It is important to be aware of the scope and limitations of real world price incentives as they are manifested in California since market perversities can lead to incentives for inefficient water use.

Wholesale agricultural surface water delivery in California is primarily performed by two agencies, the California Department of Water Resources (DWR), and the United States Bureau of Reclamation (USBR). Both of these agencies are required to price the water delivered based on the cost of repaying the bonds issued to build and operate the conveyance and storage facilities. This requirement prevents them from charging the scarcity value of water or from applying fees to encourage conservation.

The types of pricing schemes offered reflect the focus on bond repayment. Often, customers do not even pay marginal prices for water deliveries, instead having an annual fixed allocation that they purchase in bulk, which is based on acreage owned. The power to provide market-based incentives has another restriction: The USBR is required to allocate property rights based on reasonable grower needs, or beneficial use. In this "use it or lose it" framework, a grower has a disincentive to adopt conservation technologies since that could result in proving that the grower has lower water needs and lead to a reduction in water allocated. Water markets are impossible under this allocation of property rights since

any water the grower has to sell would demonstrate that grower was getting more water than needed.

Although there is limited flexibility in USBR policy, redefinitions have been made in an attempt to reduce the disincentive for conservation. First, it is now possible to classify conservation as beneficial use. However, this is based on mechanistic top down calculations that do not easily allow for individual innovation and flexibility. Second, certain water trades can be classified as beneficial use, allowing the establishment of limited water markets. Although these redefinitions do move the water policy of the USBR in the direction of conservation oriented incentives, they also demonstrate the restrictive framework that agencies such as the USBR and DWR must work within.

The limitations in USBR pricing policy reflect California's long history of uncertainty in water rights. There have been two competing water rights doctrines, appropriative and riparian. Claims made under one system were challenged under the other system, leading to a century of litigation. In recent years rights have become relatively well established. The legacy of uncertainty is still evident, however. In periods of water scarcity, or when new species are listed as endangered, the water rights of cities and agriculture are threatened. In addition, since water trading is a relatively new phenomenon in California, there is sometimes a public perception that growers should not have the right to make "too much" money from selling water, since the state owned water is supplied to them at delivery cost by government agencies, and is based on redefinitions of beneficial use. Perceptions of profiteering can lead to extensive scrutiny of trades, increasing their costs and perhaps weakening the water rights of the participants.

The politics of solidifying rights drives many of the positions held by water users in negotiations. Privacy is highly valued since public outcry can lead to lawsuits threatening water rights. Supporting water markets can be viewed as a signal that a stakeholder is obtaining "more water than they need," so even if a party stands to benefit significantly from the market, it may be in that party's interest to publicly voice reservations about the market. Similarly, if growers must establish that they deserve the water allocations that they receive, they may resist conservation programs that can imply that they have not been using their water efficiently in the past.

Other restrictions on water trading exist. For example, trades between different sectors (for example from agricultural to urban) require special approval, which can be expensive and take a great deal of time. As a result,

successful ongoing markets have been constrained to be within agricultural sectors with intersectoral trades restricted to costly, repeated negotiations between cities, agriculture, and environmentalists for each individual transaction.

Daily ongoing water markets operate in the Westlands agricultural water district. Another market exists between agricultural water districts within the San Luis Delta Mendota Water Authority (Olmstead et al., 1997). Because these markets function entirely within the same delivery agencies, and represent entirely agricultural uses they have been able to circumvent many of the obstacles that broader markets would face. Of course, this limits the benefits of the trades. Nevertheless, almost half of the water used by Westlands district flows through the market (Olmstead, 1998).

USBR sponsored trades to bring water to environmental uses are being debated in the inter-district water market. These are politically sensitive, not only for the reasons already mentioned but also because the funding for these trades is assessed from the water districts. Some water districts have demonstrated sentiment that they should not have to bid against fees already paid to the USBR when purchasing water. Nevertheless, given enough time and the continued solidification of water rights, these barriers to trade may ease.

In the meantime, however, water delivery agencies have an extremely limited ability to use water prices to encourage the efficient use of water. Since markets are limited and costly and agency pricing cannot be set based on scarcity, these agencies have been forced to look to other mechanisms to promote conservation.

## **IMPACTS OF A WEATHER INFORMATION PROGRAM**

In an attempt to encourage water conservation in agriculture given their severe restrictions on pricing incentives, the DWR instituted the California Irrigation Management Information System (CIMIS) in 1982. The CIMIS network consists of 111 weather stations across the state providing a wide range of weather related measurements to growers. The principal data product is daily regional evapotranspiration (ET). Originally, the information was provided free of cost to subscribers through dedicated modem lines. University of California extension supplemented the weather information with detailed instructions on how to take advantage of the raw data for irrigation of particular crops. It was hoped

that growers could reduce water wasted in irrigation if they had better information on daily impacts of weather on crop water use.

In a tight state budget environment, questions about the performance of the program led to inquiry about its effectiveness. Concerns about the scope of the program arose because a relatively small group of growers were the principal users of the system. Irrigation consultants were also significant users of the system, reselling value added products to growers. This motivated policy makers to question if ET provision was an appropriate role for the government or if the system should be privatized or fee based. As the system evolved, newspapers became clients and CIMIS ET data began to print in the weather section. With this, questions arose about how to prevent the spread of the information if a fee were to be charged.

To address these concerns, the University of California performed a study of the CIMIS system to compare its costs and benefits in terms of water savings and production increases. Unanticipated impacts of the system were also investigated, as was its potential for privatization or funding through user fees. This study (Parker et al., 1996) estimated that the CIMIS saved approximately one hundred thousand acre feet of water per year in agriculture. These savings were not only for growers supplied by the DWR, but also for those who got their water from the USBR or other sources. In addition, growers using CIMIS reported increased yields in spite of their water reductions.

The intensive users of the system provided most of the water savings and reaped most of the benefits. Although this was a relatively small group, the benefits and water savings they experienced provided substantial statewide impact. The combined net profits to growers resulting from the water cost savings and increased revenues from yields were estimated to be 32 million dollars annually. This was significantly more than the eight hundred thousand dollar annual budget of the program.

These users tended to face high water costs, have fast draining soils, and high value crops. Irrigation technology effected benefits as well. Most of the intensive users of the program used pressurized irrigation systems. A minority among the intensive users, growers with nonpressurized irrigation systems such as flood and furrow, experienced about a 5 percent in water savings while growers using drip and sprinkler systems experienced savings of about 15 percent. In the interviews many growers reported that they switched to

drip or sprinkler systems in response to the availability of the CIMIS program.

The report found that it would be difficult to privatize or charge fees for the CIMIS information. Growers could share the information almost costlessly. Thus, to a certain extent the weather information had public good characteristics. Although private consultants were providing weather information to growers for a fee, they were developing value added, individually tailored products. Because these products were specific to individual growers, the problem of the costless spread or pirating of the information was not an issue for a value added product. An interesting pattern of provision of public information to private users was noticed. The CIMIS system was used for the more public component of the information while individual consultants stepped in to provide the private part, usually using the CIMIS system as an initial starting point for their work. The potential for "pirating" the information was a significant deterrent preventing privatization of the core weather product or funding it through fees.

Many unanticipated uses were discovered for the weather information. Growers were finding that they could use it to increase the quality of their crops, for example, by optimally stressing wine grapes or preventing melons from rotting in standing water. The reductions in standing water were also beneficial for pest control, reducing pesticide use and associated costs (Daane et al., 1995). Making use of the entire set of weather variables, growers were able to predict pest outbreaks and reduce pesticide applications to those particular situations.

As Internet use became more widespread, CIMIS information was made available in that form. Since the weather information could be used by groups outside of the jurisdiction of the DWR, these groups were able to develop methods to take advantage of the system, providing unanticipated water savings. Much like the Internet itself, the availability of the weather program encouraged innovations for unexpected uses as clients discovered ways in which the system could benefit them. These users included fire control districts and city and county planners. Because of the high price of urban water and high value for the quality of their amenities, urban landscaping and golf courses were among the most intensive users of the system and had the highest rates of water savings and benefits from the system. Even though these groups were far outside of the pricing mandate that the DWR had, their water use was heavily impacted by its information program.

Although it is clear how an information system can provide benefits to unanticipated groups, the reasons for the other results observed are not necessarily so evident. This paper proceeds to explain the link between weather information and agricultural production, why growers choose to use the program, how is it possible to simultaneously achieve water savings and yield increases, and perhaps most importantly, how information interacts with other incentives.

## ADOPTION, PRECISION, AND INFORMATION

The literature on precision technologies demonstrates how water use is related to irrigation technology choice and why efficient irrigation systems require quality information in order to be effective. In this literature, waste in irrigation systems arises from growers being constrained to a uniform application of water when actual crop water consumption vary from day to day. Hot windy days dry out crops more than cool moist days.

To quantify weather effects on water demands, irrigation engineers use daily evapotranspiration or ET (Snyder et al., 1981). ET is the volume of water that evaporates from and transpires through a crop in a day due to that day's weather. If an inflexible irrigation system prevents a grower from adjusting to the water demands of different days, that grower is forced to decide on the compromise homogenous application level. On days with low ET, the compromise amount applied is too much water and the excess deep percolates or drains off the field to be wasted. On days with a high ET, the compromise level of application offers too little water, and the crops dry out, reducing yields. Aggregating over the growing season, water is less wasted and potential yields are sacrificed.

A precision irrigation technology addresses this problem by allowing the grower to tailor water application to the appropriate amount for each day. In this way, a precision system can simultaneously improve water efficiency and increase yields. Caswell and Zilberman (1986) use the concept of irrigation efficiency to model this process. In their framework, production ( $y$ ) is a function of effective water ( $x_e$ ) which is the water actually absorbed by the plant, so  $y = f(x_e)$ . This is in contrast to the applied water ( $x$ ) which is the amount applied to the field over the growing season. Irrigation efficiency ( $\mathbf{a}$ ) is defined as the ratio of effective water to applied water, or  $\mathbf{a} = x_e/x$ . Low precision technologies, such as furrow irrigation, have efficiencies of about 60

percent while high precision technologies, such as computer controlled drip systems, can have efficiencies of above 90 percent.

These technologies are information intensive. Gains cannot be realized if the grower does not have information on the changing daily water requirements of the crops. Therefore irrigation efficiency is a function of the information quality, the precision of the application technology and the heterogeneity of the production sub-units (Osgood, 1999). Micro unit variability ( $\mathbf{S}$ ) is a measure of the heterogeneity of the production sub-units. There is locational variability of the dynamic of depletion of soil moisture and soil capacity to store water for absorption by the plants. Depletions in soil moisture are driven by temporal variations in ET, filtered by the water holding capacity of the soil and crop properties. High micro unit variability lowers irrigation efficiency as sub optimal amounts of water are applied on each micro unit (day). Using weather information and precision irrigation technologies, a grower can counter the negative effects of high micro unit variability. Therefore the benefit of these technologies is highest when there is a great deal of micro unit variability and diminishes for those facing low levels of variation. Because farms have different weather, crop, and soil characteristics, micro unit variability changes from farm to farm. The benefits of precision technologies therefore vary depending on farm characteristics.

Increasing the quality of daily ET information improves irrigation efficiency yielding an intensive (production based) effect on water use. Obviously, this effect is most pronounced for growers who have substantial micro unit variability and who are using precision irrigation systems (Osgood, 1999). Because improvements in daily ET information increase irrigation efficiency more for high precision systems than for low precision systems, information improvements make precision irrigation systems more attractive in terms of profits from increased yields and water savings. This provides the extensive effect: It is an incentive for the adoption of efficient irrigation systems.

The threshold adoption framework of David (1975) clearly represents the incentives behind this process. Assume a population of growers with heterogeneous levels of micro unit variability, and a choice of upgrading from a low precision irrigation technology ( $A_1$ ) to a higher precision technology ( $A_2$ ) at a given level of ET information quality ( $I$ ). It is worthwhile to invest in the higher precision technology if its yield and water savings benefits exceed the investment cost of the

technology. Equation 1 represents the adoption threshold and implicitly determines  $S^*$ , the threshold micro unit variability of adoption. At levels of micro unit variability above the threshold it is worthwhile to invest in the new technology, while at lower levels it is not worthwhile to adopt.

$$[P_{x_2}y(a_{A2Ls^*x_2^*}) - P_{x_2}x_2^*] - [P_{x_1}y(a_{A2Ls^*x_1^*}) - P_{x_1}x_1^*] = C \quad (1)$$

Adoption is mapped to the population by observing the distribution of individual micro unit variability, as in Figure 1. If the solid line illustrates the threshold micro unit variability at which it is worthwhile to adopt, the population right of the solid line would adopt while the population to the left of the line would not. Increasing the information quality improves the efficiency gain of higher precision technologies and therefore shifts the threshold to the left to the dashed line. The integral of the population density between the two lines represents the group of new adopters and illustrates the adoption impact of providing subsidized weather information.

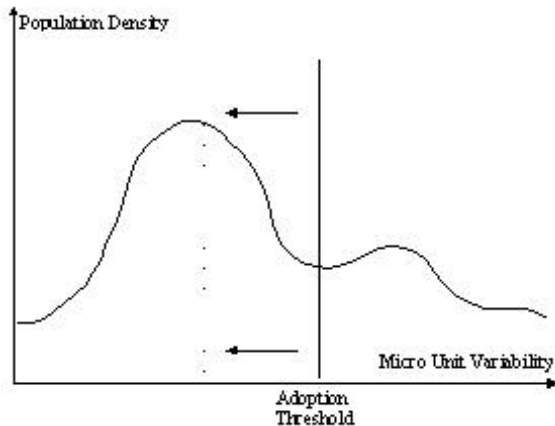


Figure: 1 Adoption Threshold

This shift can be accomplished through other incentives. Increasing the marginal price of water or of the agricultural output leads to improvements in the profit differential, shifting the threshold micro unit variability to the left and increasing adoption. Because the investment cost includes the cost of physical infrastructure as well as the human capital investment of learning how to produce using the new system, adoption can also be influenced by reducing the learning costs through education and outreach (Wolf & Nowack, 1994).

The market failures associated with the pirating of information, prevented private sector from providing that type of product, leaving the government to fill that role. From a policy perspective, the ease of spread of information was found to be an advantage. The more information “pirating” that occurs, the more successful the program. Not imposing users fees is optimal from a social prospective. The wider the spread of the information, the greater the incentives for conservation.

Because there are two market failures, the cost of waste and public good problems leading to the under provision of information, market forces will lead to optimal adoption and use of precision systems only if the true shadow value of water is faced by growers and if there are no market failures associated with information. Thus, even if California growers faced appropriate prices for water, there would be inefficient water use from the market failures due to the public good characteristics of weather information. Therefore there is a government role in providing growers with weather information. In addition, Osgood (1999) showed that if prices did not accurately reflect the scarcity value of water, an information “super-subsidy” (provision of weather information exceeding that necessary to counteract the public good market failures) is an effective tool to improve conservation.

## CONCLUSION

Weather information allows growers to take advantage of the flexibility of conservation technologies to respond to changes in water needs over time, saving water on some days and increasing yields on others. Therefore, information provides more yield and water savings benefits to conservation technologies than to lower precision, less flexible irrigation systems. This causes conservation technologies to be relatively more profitable and their adoption worthwhile for a larger segment of the population.

The groups that will take advantage of these technologies will be those who have high value crops and high water costs resulting in relatively higher potential profit increases. Because the gains arise from an ability to adapt water applications to heterogeneous micro unit demands, growers who face higher variation due to weather, crop, or soil characteristics are also more likely to invest in conservation technologies. In addition, unexpected groups may be affected by the program. Information programs have a spillover potential leading to unanticipated benefits and conservation far beyond the original mandates of regulatory agencies.

Even with weather information provision, constraints preventing efficient water markets or scarcity pricing of water continue to reduce incentives for adoption. In Parker et al. (1996), it was noted that the biggest disincentive for the adoption of precision technologies was low water prices. However, information programs increase the responsiveness of growers to react to other incentives as they evolve, either through gradual policy change or because of a crisis. Therefore, they provide an important policy tool to compliment the pricing mechanisms that are or may become available.

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