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The Effects of Pricing Policies on Water Conservation and Drainage

Margriet Caswell, Erik Lichtenberg, and David Zilberman

A general model of adoption of input-conserving technologies by competitive firms is introduced using drip irrigation as an example. An environmental regulation such as a drainage effluent charge is shown to influence adoption. Early adopters are likely to be producers with less efficient fixed assets (land of low quality or antiquated capital), higher input costs (higher water prices or greater depth to groundwater), and in more environmentally sensitive regions. Simulations show that drainage regulations can be expected to play a major role in adoption of more efficient irrigation technologies in California. Thus, conservation may be a key to solving resource scarcity problems and reducing external environmental costs.

Key words: drainage, irrigation, pollution reduction, technology adoption, water conservation.

Considerable interest has been expressed in the potential of input-conserving technologies as responses to problems of resource scarcity. Adoption of water-conserving irrigation technologies is often cited as a key to dealing with growing pressures on water supplies in the arid western United States. Recently, however, high external costs associated with agricultural drainage and runoff have added a new impetus to improving water-use efficiency. The contamination of the Kesterson Wildlife Refuge by agricultural drainage is considered the precursor of widespread problems of a similar nature. Cost-effective solutions to resource scarcity and externality problems are needed. An increase in agricultural water-use efficiency can be stimulated through increased water prices, the adoption of water-conserving irrigation technologies, and the imposition of pollution taxes. This paper will assess the relative effects of each of these policy alternatives on yields, water use, profitability, and the quantity of drainage effluent.

This analysis builds on the recent work by Caswell and Zilberman (1985, 1986) that presented a model for analyzing the adoption of input-conserving technologies. That model has been expanded and generalized to include external effects of input use and the role of environmental policies in conserving resources and reducing pollution. The conceptual model is based on the profit-maximizing behavior of farmers with varying land quality. While the model is presented in terms of irrigation and drainage management, the concepts are applicable to a broad variety of inputs used in agricultural or industrial production. A numerical simulation model based on irrigation and drainage in cotton production in the western San Joaquin Valley, California, illustrates the relative importance of conservation and pollution policies for solving a major agricultural problem.

Technology Selection by the Profit-Maximizing Firm

In this section, we will describe several aspects of the model, including the production function, irrigation effectiveness, the irrigation cost equation, and the pollution general function, and then the optimization problem.

The Model

The conceptual farm-level model has several components which characterize the crop, the

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technologies, and the policies that affect decision making. For simplicity, two irrigation technologies—a traditional one with $i = 0$ and a modern one with $i = 1$—are assumed.

The production function. A single crop is produced with a constant return-to-scale technology. Let $q = f(e)$ be a per-acre production function, where q denotes output per acre, e is effective water (water actually taken up by the crop's root system), and $f(\cdot)$ has the regular properties of a neoclassical production function, $f(0) = 0, f'(\cdot) > 0, f''(\cdot) < 0$.[1]

Irrigation effectiveness. The amount of water utilized by the crop (effective water) is seldom the same as the quantity of water actually applied to the field (applied water). Irrigation effectiveness is the ratio of applied to effective water and is assumed to depend on the irrigation system and land quality. The measure of quality used here is the land's ability to retain water; it depends on soil permeability and water-holding capacity and the slope of the land. Let a_i denote applied water per acre under technology i and let α be a land quality index assuming values from 0 to 1. Irrigation effectiveness is formally defined as $h_i(\alpha) = e_i(\alpha)/a_i(\alpha)$.[2] The quality index, α, is scaled to correspond to irrigation effectiveness under the traditional technology [i.e., $h_0(\alpha) = \alpha$]. Modern irrigation technologies are assumed to increase irrigation effectiveness for $\alpha < 1$, i.e.,

$$\alpha < h_1(\alpha) \text{ for } 0 < \alpha < 1, \text{ and } h_1(1) = 1.$$

Modern irrigation technologies can be interpreted as land quality augmenting because they augment the soil's water retention capacity. Modern technologies may also increase the effectiveness of other inputs as occurs when fertilizers and pesticides are applied through sprinkler or drip irrigation systems. For ease of exposition, this paper focuses on a single input, water.

Irrigation cost equation. Assuming constant returns to scale, irrigation cost per acre can be written as $c_i(\alpha) = I_i + a(v_i + w)$ where I_i is fixed cost per acre—mainly the nonirrigation costs of production and cost of equipment and setup of irrigation system.[3] For simplicity, the fixed cost of the technology does not depend on land quality in this analysis. Modern technologies typically have higher fixed costs than traditional ones, i.e., $I_1 > I_0$. The variable cost per acre-foot of water applied consists of the price of water, w, and application cost associated with technology i, which is assumed independent of land quality, v_i. The price of water will vary according to the location of the farm or the depth of the well. The application cost includes the pressurization requirements for each technology which only applies to sprinkler and drip irrigation technologies.

Pollution general function. The water not taken up by the crop may be a source of environmental damage. Deep percolation may cause waterlogging, which may be mitigated by drainage. Drainage water, however, may impose large social costs. Runoff water may be another source of pollution. Let the pollution coefficient, $g_i(\alpha)$, denote the fraction of water applied by technology, i, on land of quality, α, that is not utilized by the crop and is environmentally damaging: $g_i(\alpha) \leq 1 - h_i(\alpha)$. It is reasonable to assume that more water-efficient irrigation technologies have lower pollution coefficients, i.e., $g_1(\alpha) \leq g_0(\alpha)$, and that pollution coefficients decline as land quality improves, $g_i'(\alpha) < 0$. Finally, let discharge per acre under technology, i, be denoted by $b_i = a_i \cdot g_i(\alpha)$.

[1] The analytical framework can be expanded to production functions with more than one input. Little additional insight was gained in the case where two inputs (effective water and effective fertilizer) were analyzed, and the costs in terms of analytical complexity were substantial. Clearly, multi-impact considerations should be incorporated in empirical applications where data are available.

[2] The notion of irrigation effectiveness presented here is similar to the one presented in Vaux and Pruitt. Irrigation efficiency may vary with effective water, and a general formulation should present it as $e_i(\alpha)/a_i(\alpha) = \bar{h}_i(\alpha, e_i)$. The experimental results of Stewart et al. suggest that, for a given land and irrigation technology, efficiency is constant for most levels of effective water. Irrigation efficiency tends to decline with effective water only when yield per acre approaches its maximum level [i.e., $\partial\bar{h}/\partial e_i < 0$ only for $e_i \rightarrow e^*$ where $f(e^*) = \max f(e)$]. Most outcomes of interest are likely to occur when the internal solution, e_i, is below e^* and the use of $h_i(\alpha) = e_i(\alpha)/a_i(\alpha)$ is appropriate for such situations. Furthermore, experimentation with more complex formulations yielded little additional insight.

[3] The assumption of constant returns to scale is reasonable for the main cost items associated with adoption of modern irrigation technologies—pipes, emitters, and filters. In some areas, volume discount may be a source of increasing returns to scale. Another source of economies of scale may be learning, design and training, and reorganization associated with adjustment to the new technology. These causes of scale effect do not seem substantial for the San Joaquin Valley because most farms there are large. Introduction of scale consideration to the conceptual analysis will neither affect most of the findings nor add much insight.

The Optimization Problem

A profit-maximizing farmer's choice of a water application rate and irrigation technology can be solved via a two-stage procedure. The farmer will first choose the optimal amount of water for each technology and then choose the irrigation technology yielding the highest profit. Let $\Pi_i(\alpha)$ denote quasi-rent per acre that can be earned using technology, i, then

$$(1)\quad \Pi_i(\alpha) = \max_{a_i} \{Pf(h_i(\alpha)\cdot a) - I_i - a(v_i + w) - x\cdot a\cdot g_i(\alpha)\},$$

where P is the price of the crop, x is antipollution tax (charge per unit of pollution), and $x\cdot a\cdot g_i(\alpha)$ is the internalized cost of pollution. Π is quasi-rent because it represents the operational profit only and does not include the rental rate for the land.

The optimal level of applied water is found by solving

$$(2)\quad Pf'(h_i(\alpha)\cdot a_i(\alpha))\cdot h_i(\alpha) = v_i + w + xg_i(\alpha)$$

for $a_i(\alpha)$. The optimal quantity of water to apply will be a function of land quality and the technology used. Let $u_i^a(\alpha)$ denote the cost of applied water and $u_i^e(\alpha)$ represent the effective price of water so that

$$(3)\quad u_i^a(\alpha) = w + v_i + xg_i(\alpha), \text{ and}$$
$$u_i^e(\alpha) = u_i^a(\alpha)/h_i(\alpha);$$

$u_i^e(\alpha)$ reflects all the costs of obtaining one unit of effective water on land of quality, α, with technology i. Equation (2) can be written as

$$(4)\quad Pf'(e_i) = u_i^e,$$

which is a more familiar form of the marginal efficiency condition for resource allocation. The choice of irrigation system will depend on the relative values of profitability. The technology with the highest quasi-rent will be selected if it can cover the land rent.

Technology Choice with a Pollution Tax

This section compares yields and water use under traditional and modern technology and determines conditions for their technology adoption when there is a tax on drainage effluent. The concept of elasticity of marginal productivity (EMP), denoted by $\varepsilon \equiv -f''(e)\cdot e/f'(e) \geq 0$, plays a key role in the analysis (Caswell and Zilberman 1986). For a given technology at a given location, the price elasticity of water demand is $1/\varepsilon$. Thus, a high EMP corresponds to inelastic water demand and vice versa. In terms of the classical three phases of production, EMP is zero when marginal productivity is at its peak and is infinite when marginal productivity is zero. In the economic range of water use (phase II of the three classic phases of production), EMP is positive and it increases as effective water increases. Another useful concept is the elasticity of production with respect to the effective variable input use represented by $\phi \equiv f'(e)\cdot e/f(e) \geq 0$.

The Impact of Adoption on Yield, Water Use, and Drainage Quantities

A switch from the traditional to the modern technology involves simultaneous changes in irrigation efficiency of $h_1(\alpha) - h_0(\alpha)$ and in applied water cost of $u_1^a(\alpha) - u_0^a(\alpha)$. The differences in yield and water use per acre between the technologies can thus be approximated by[4]

$$(5)\quad q_1 - q_0 \doteq = \frac{\phi}{\varepsilon}\left[\frac{h_1 - h_0}{h_0} - \frac{u_1^a - u_0^a}{u_0^a}\right], \text{ and}$$

$$(6)\quad a_1 - a_0 \doteq -\frac{a_0}{\varepsilon}\left[\frac{h_1 - h_0}{h_0}(\varepsilon - 1) - \frac{u_1^a - u_0^a}{u_0^a}\right].$$

The difference in pollution per acre between the techniques is

$$(7)\quad b_1 - b_0 = a_0(g_1 - g_0) + g_1(a_1 - a_0).$$

Using (6), $b_1 - b_0$ can be approximated by

$$(8)\quad b_1 - b_0 \doteq a_0(g_1 - g_0) - \frac{g_1 a_0}{\varepsilon}\left[\frac{h_1 - h_0}{h_0}(\varepsilon_0 - 1) - \frac{u_1^a - u_0^a}{u_0^a}\right].$$

Equations (5), (6), and (8) lead to the following conclusions:

(*a*) Adoption of the modern technology tends

[4] The marginal impacts are essential for the approximation. For example, using

$$q_1 - q_0 \doteq \frac{\partial q_0}{\partial u_0^a}[u_1^a - u_0^a] + \frac{\partial q_0}{\partial h_0}[h_1 - h_0] \text{ and } \frac{\partial q}{\partial u_1^a} = -\frac{\phi}{\varepsilon u_0^a}; \frac{\partial q}{\partial h_0} = \frac{\phi}{\varepsilon h_0},$$

one can obtain equation (5).

to increase (reduce) optimal yield when the proportional gain in the irrigation efficiency associated with adoption of modern technology is larger (smaller) than the proportional increase in applied water cost associated with the adoption. For every quality, a critical applied water price separates low water price locations with $q_0 > q_1$ and other locations with $q_1 > q_0$. Because of the lower pollution coefficient of the modern technology ($g_1 < g_0$), a pollution tax increase tends to add to the range of water prices for which $q_1 > q_0$. The relative yield effect increases for higher water prices and lower land qualities.

(*b*) The adoption of the modern technology tends to save water unless EMP is quite low. The critical EMP above which $a_1 < a_0$ is

$$(9)\quad \varepsilon^* = 1 - \left[\frac{u_0^a - u_1^a}{u_0^a}\right]\left[\frac{h_0}{h_1 - h_0}\right] < 1.$$

Under most circumstances, the EMP is smaller than one and, therefore, $a_1 < a_0$. Special situations may arise in which crop yield is responsive to an increase in effective water, and adoption of modern technology will increase applied water.

Equations (6) and (9) suggest that a pollution tax may substantially affect the nature of the impact on water use of the adoption of new irrigation technologies, especially in situations where (*i*) initial costs of pollution per unit of water (xg_0) are large relative to water price and application cost, and (*ii*) the new technology almost eliminates pollution ($x(g_0 - g_1) \cong xg_0$). A pollution tax increases the likelihood that adoption will increase both yield and water use. Moreover, the relative savings from adoption in cases where the modern technology uses less water are smaller than would be expected without the tax.

(*c*) Condition (8) indicates that the adoption of a modern irrigation technology would reduce the quantity of contaminated drainage water by (*i*) reducing pollution per acre from any given application of water [expressed by $-a_0(g_1 - g_0)$] and (*ii*) reducing the quantity of water applied per acre when EMP is high. An increase in the drainage charge will increase the pollution savings from switching technologies, but the extent will be determined by the characteristics of the crop and the technologies.

The Characteristics of Adopting Farms

In the formulation of the model, input use and output were assumed equal for the technologies at the highest land quality. For such "perfect" conditions, it was also assumed that the pollution coefficient is zero for all technologies. Because $I_1 > I_0$ for all land qualities, the traditional technology will be more profitable than the modern one when $\alpha = 1$. As land quality declines, profit declines faster under the traditional technology than under the modern technology (the gaps between $h_1(\alpha)$ and $h_0(\alpha)$, and $g_1(\alpha)$ and $g_0(\alpha)$ tend to increase as α declines from $\alpha = 1$). If the new technology is adopted at all, it will be utilized on lower land qualities than will the traditional system.

Two land-quality types play an important role in analyzing the effects of exogenous changes on adoption. One is α_i^m, the land quality for which the use of the technology i results in zero operational profit, and the other is α^S, for which both technologies yield the same profit per acre. The modern technology is utilized at the land quality range α_1^m to α^S, and the traditional quality is utilized at the range α^S to 1. Total differentiation of the equilibrium conditions $\Pi_i(\alpha_i^m) = 0$ and $\Pi_1(\alpha^S) = \Pi_0(\alpha^S)$ with respect to output prices, applied water costs, and investment costs

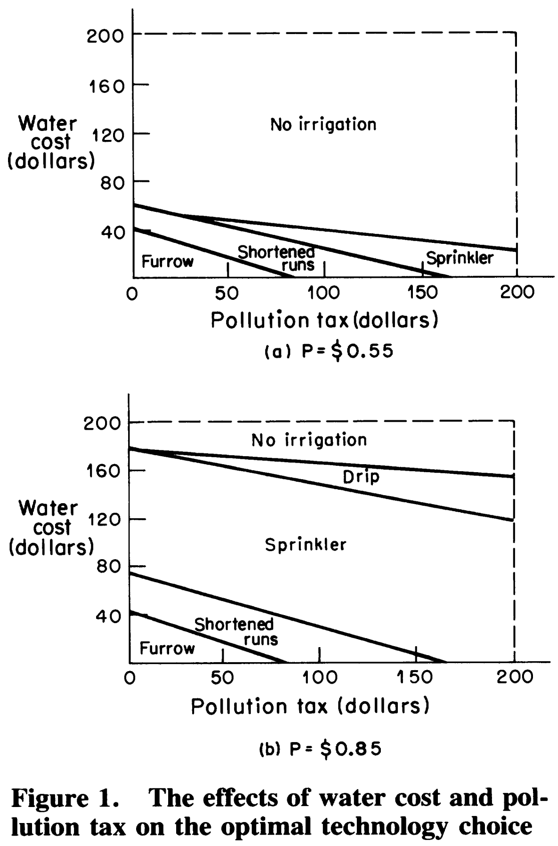

Figure 1. The effects of water cost and pollution tax on the optimal technology choice

leads to several conclusions concerning the characteristics of adopting farms. The adoption of modern technology will increase as (*i*) the gap in the fixed cost per acre between modern and traditional technologies ($I_1 - I_0$) declines and (*ii*) the difference in the application cost ($v_1 - v_0$) declines.

An increase in pollution tax tends to increase α^S, thus encouraging owners with higher quality land to switch to the modern technology. On the other hand, a higher pollution tax will increase the quality at which production ceases, α_i^m. Thus, a pollution tax may encourage the adoption of the modern technologies in locations where it has not been adopted before while reducing the irrigated land base at the same time. Because of the higher yield associated with the switch to the modern technology, overall output may actually increase when a pollution tax is introduced.

In sum, introduction of a pollution tax is likely to reduce water use and pollution by (*i*) reducing water use and pollution on farms using traditional methods; (*ii*) encouraging adoption of the modern, less polluting technology; and (*iii*) encouraging retirement of low quality lands.

A Numerical Simulation Model

The following example is based on the general characteristics of cotton production in the western portion of California's San Joaquin Valley. The example illustrates the effects of a pollution tax on technology choices, crop yields, water use, and drainage levels. Cotton grown in this drainage area has an evapotranspiration (ET) requirement net of effective precipitation of 2.5 acre-feet (AF). The maximum yield that can be produced if the net ET requirement is met ranges from 1,200 pounds per acre to 1,400 pounds per acre depending on soil fertility. There is also yearly variability in production. For instance, the average yield of cotton in the drainage area was 1,117 pounds per acre in 1984 and 1,350 pounds per acre the following year. Four irrigation technologies are compared: (*a*) traditional (furrow), (*b*) shortened runs (modified furrow), (*c*) sprinkler, and (*d*) drip.[5] The systems are listed in the order of the fixed costs and application costs (both increasing from 1 to 4).

The conceptual analysis in Caswell and Zilberman (1986) and the estimates reported in Hexem and Heady suggest that yield can be reasonably approximated as a quadratic function of effective water, i.e., $q = a + be - ce^2$. To obtain the parameters for the numerical example presented here, the results in the State Water Resources Control Board report and Hanemann et al. were used. These results suggest that a maximum yield of 1,300 pounds per acre can be obtained with an effective annual water application of 2.5 acre-feet and that a yield of 1,040 pounds per acre would result if 1.75 acre-feet of effective water is used. These assumptions imply that yield per acre for the *i*th technology is

$$q_i = -1{,}589 + 2{,}311(h_i a_i) - 462(h_i a_i)^2.$$

The analysis is conducted for typical land in the area which has irrigation efficiency of .6 under the traditional technology. The irrigation efficiency parameters (h_i), deep percolation coefficients (g_i), pressurization cost (v_i), and fixed costs per acre (I_i) for each of the technologies are shown in table 1.[6] Optimal water use, output, drainage, and profit under each technology were derived for water prices ranging from \$0 to \$300 per acre-foot in \$25 increments, drainage charges ranging from \$0 to \$200 per acre-foot (AF) in \$50 increments, and output prices ranging from \$0.55 to \$0.85 per pound.

Some patterns of behavior emerged from the results. Profitability is sensitive to price changes, and there is a wide range of situations with relatively low output price and high drainage and water cost where none of the technologies generates positive profits. Among cases with positive profits, there is little variation of yield per acre and substantial variations of drainage and applied water per acre level. Most of the variations of applied water and drainage are between technologies, while the within-technology variations are not large. In particular, yields per acre of profitable operation range from 1,300 pounds to 1,266 pounds per acre, and adoption of modern technology increases yield by a small amount. Thus, under the price ranges considered here, production is close to maximum output.

Water use per acre varies between 4.17 and 3.69 AF with furrow, between 3.57 and 3.18

[5] These four irrigation systems are representative of the basic types of irrigation rather than a complete list of options.

[6] Pressurization costs are derived assuming a lift cost of 13c/AF per foot and that the pressurization requirement of drip irrigation is equivalent to a lift of 70 feet and that of sprinkler is equivalent to a lift of 110 feet. Fixed costs include irrigation equipment costs and costs of inputs other than water. The figures reflect the assumption that drip irrigation is likely to be used for applications of fertilizers, and fertilizer costs are likely to decline by \$20 per acre.

Table 1. Irrigation Technology Parameters

Technology	Irrigation Effectiveness	Percolation Coefficient	Pressurization Costs per Acre Foot	Fixed Cost per Acre
	h_i	g_i	v_i	I_i
Furrow	0.60	0.1750	0	500.00
Shortened runs	0.70	0.1330	0	517.00
Sprinkler	0.80	0.0875	1.3	548.00
Drip	0.95	0.0400	9.1	633.00

Source: Hanemann et al.

AF with shortened runs, between 3.13 and 2.79 AF with sprinkler, and between 2.63 and 2.41 AF with drip. Similarly, drainage per acre ranges between .73 to .65 AF with furrow, between .47 and .41 AF with shortened runs, between .27 and .24 AF with sprinkler, and between .11 and .10 AF with drip. The figures for furrow are consistent with field observations in the San Joaquin Valley.

The results highlight the crucial role of technology changes in efforts to reduce drainages and water use. Drainage per acre can be reduced at most by about 11% if furrow technology is retained but can be reduced by up to 85% for a switch from furrow to drip. Therefore, prices can have a major effect on conservation mostly through their impact on technology choices.

Figure 1 presents the optimal technology choice for each water price per pollution charge combination for two output price levels. It shows that increases in output price affect technology choices mostly by extending the range of water prices and drainage charges under which operation is profitable. The ranges of water prices and drainage charges for which furrow irrigation and shortened runs are optimal change relatively little when the price of cotton rises from a low of \$0.55 per pound to a high of \$0.85 per pound. On the other hand, the ranges of water prices and drainage charges for which sprinkler and drip are optimal change markedly, primarily because the higher output price offsets the higher fixed costs of these technologies. Because the main effects of adopting more efficient technologies are reductions in water use and drainage, drip will be the most profitable of the four technologies for the highest combinations of water prices and drainage charges; sprinkler is the most profitable for the next highest. The savings in water cost and drainage fees are insufficient to offset the increased fixed costs associated with adoption of drip and sprinkler irrigation, however,

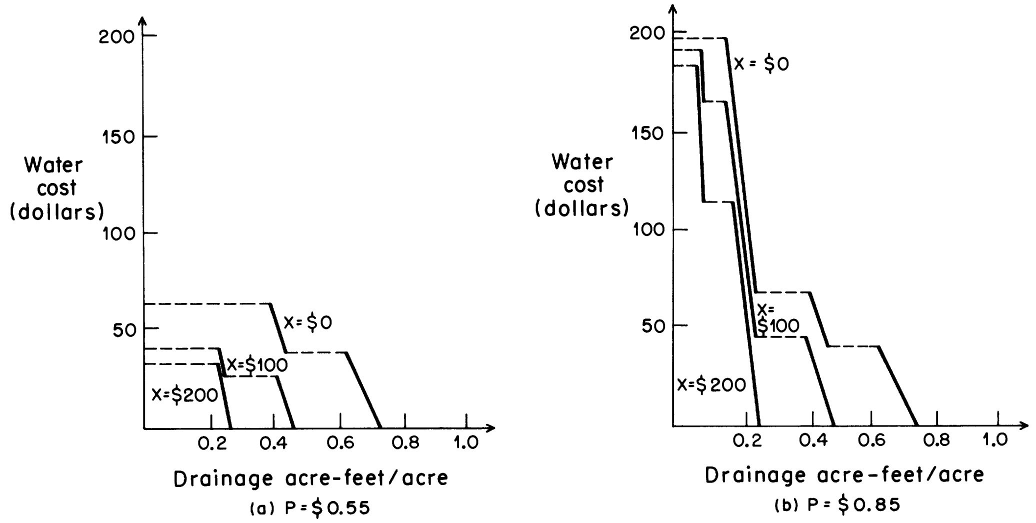

Figure 2. The effects of water cost and pollution tax, X, on the quantity of drainage

so that output price must be relatively high before these more efficient technologies will be adopted.

Because the volume of water applied is considerably higher than the volume of drainage generated per acre, a $1.00 increase in water price will have a much stronger impact on the switch to a more irrigation-efficient technology than a $1.00 increase in drainage cost. The slopes of the lines separating the technology regions (the water and drainage price ranges associated with specific technologies) in figure 1 reflect this. This situation also suggests that water price is the dominant factor affecting the farmers' demand for both water and drainage.

Figure 2 shows the drainage volume per acre as a function of water price for three drainage charge levels and for low ($0.55 per pound) and high ($0.85 per pound) cotton prices. The resulting demand curves are discontinuous because of the switch in technologies induced by water cost changes. These demand curves can be used to analyze the impact of pricing policies on drainage volumes, a major issue in California. It has been suggested that increasing water prices will "solve" the drainage problem by encouraging conservation. Figure 2a illustrates that, if the output price is low, this approach has limited usefulness if keeping land in production is also desired. Even if there were no drainage charge (pollution tax), farms would go out of business if water costs exceeded $50 per AF. Moreover, under low output prices, the use of water price and drainage charge increases will not reduce drainage below .26 AF per acre. Although this is more than a 64% reduction in drainage compared to the present situations, it may not be enough to satisfy strict environmental requirements.

Drainage can be reduced to about 0.09 AF per acre through adoption of drip irrigation, but this reduction will be economically feasible only when output price is high. For example, when the price of cotton is $0.85 per pound, the price of water is $125 per AF, and the drainage charge is $200 per AF, water use can be reduced by 40% and drainage by 86% compared to the case of a very low water price and no drainage charge, with a less than 1% reduction in output. Under more likely conditions, for example, a cotton price of $0.70 per pound, a water price of $25 per AF (roughly the current average price of water delivered to the farm gate in this area), and a drainage charge of $100 per AF (roughly the level needed to meet a selenium standard of 2 parts per billion, as estimated by the California State Water Resources Control Board), farmers in this area would switch to sprinkler, reducing water use by only 25% and drainage by 62%.

An effective way of achieving greater reductions in water use and drainage is to reduce the fixed costs farmers incur by adopting drip irrigation. An annual subsidy of $100 per acre would make drip the most profitable technology even for very low output and water prices. An annual subsidy of about $70 per acre would make drip the most profitable technology if water price is $50 per AF. Adding a drainage fee of $100 per AF to this scenario reduces the requisite annual subsidy to about $45 per acre (less than $0.04 per pound of cotton). If the pollution tax were increased to $200 per AF, only a $30 per acre subsidy would be needed. Thus, even when attaining a drainage goal requires subsidization of a modern technology, the subsidy can be combined with a drainage fee to reduce substantially the government expenditure.

The high cost of monitoring of drainage may hinder implementation of drainage charges. This problem may be overcome by using the drainage coefficients (g_i's) and actual water use to estimate drainage under each technology. In essence, this approach introduces extra water charges that vary according to the technology. For example, a $100 per AF drainage charge translates to a $17.50 per AF increase in the price of water applied with furrow, $13.70 per AF under shortened runs, $8.75 per AF under sprinkler, and $4.00 per AF under drip.

Conclusions

In the case of agricultural water management, the results obtained here suggest that environmental considerations may become a major incentive for adoption of water-conserving irrigation technologies, such as drip and sprinkler irrigation methods. In general, adoption is more likely among growers having lower quality land, higher value crops, a high purchase price for water or greater depth to groundwater, and more severe drainage problems. Similar considerations apply to a broad variety of technological choice problems, e.g., adoption of integrated pest management. There are also many nonagricultural technologies that can be analyzed using this framework—energy-efficient industrial equipment, vehicles, and consumer appliances.

The model presented here is a static one that abstracts from several important facets of adoption decisions. Important extensions include incorporating within-firm heterogeneity such as variations in land quality within a field (e.g., Knapp, Dinar, and Letey), aggregation to the industry level and, most important, dynamic considerations such as the impacts of changes in resource scarcity and environmental damage over time on the adoption process.

Public research and extension activities should be another important element of a policy aiming to induce adoption of modern irrigation technologies to reduce drainage. Applied research may be needed to fine tune modern technologies, such as drip and low-energy precision application (LEPA) irrigation, to the local conditions and modify production procedures to incorporate them smoothly. Research aiming at improving the design and reducing the fixed cost of high efficiency may also be worthwhile. Low-volume irrigation technologies are relatively new, and they are likely far from realizing their full economic potential. Further research may be able to generate the extra $50 per acre (in form of reduced investment cost or higher yield) required to make these technologies most profitable with reasonable water and cotton prices and a drainage fee of $100 per AF. Extension and education activities may also reduce the adjustment costs of adoption, for example, educational and training costs, rearranging production plans, and risk-bearing costs associated with subjective uncertainties regarding the properties of the new technologies.

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