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Comparing the Cost-Effectiveness of Water Conservation Policies in a Depleting Aquifer: A Dynamic Analysis of the Kansas High Plains

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This research analyzes two groundwater conservation policies in the Kansas High Plains located within the Ogallala aquifer: 1) cost-share assistance to increase irrigation efficiency; and 2) incentive payments to convert irrigated crop production to dryland crop production. To compare the cost-effectiveness of these two policies, a dynamic model simulated a representative irrigator's optimal technology choice, crop selection, and irrigation water use over time. The results suggest that the overall water-saving effectiveness can be improved when different policy tools are considered under different conditions. High prevailing crop prices greatly reduce irrigators' incentive to give up irrigation and therefore cause low enrollment and ineffectiveness of the incentive payment program. In areas with low aquifer-saturated thickness, the incentive payment program is more effective, whereas in areas with relatively higher water availability, the cost-share program could be a better choice.

Key Words: cost-share program, incentive payments, Ogallala aquifer, dynamic optimization, groundwater conservation

JEL Classifications: Q30, Q32, Q38

Water scarcity is a major problem worldwide and one that is expected to be exacerbated in many regions by climate change and by population growth. Because irrigated agriculture is a major consumer of water in these regions, growing scarcity issues have prompted a renewed policy focus on agricultural water conservation.

One of the largest water-scarce agricultural regions in the world is the High Plains in the central United States, where land use is dominated by irrigated agriculture supplied by the Ogallala aquifer. The aquifer underlies portions of eight states from South Dakota to Texas and in many areas has been in steady decline for decades. In the Kansas portion of the Ogallala aquifer, irrigation consumes approximately three million acre-feet of water per year, which accounts for over 90% of total groundwater withdrawal in the state. Given the current decline rate, certain intensively irrigated areas in western Kansas have an estimated usable lifetime of the aquifer less than 50 years and in some areas, the point of effective exhaustion has already been reached.

The Ogallala aquifer is a common pool resource. The groundwater stock is not individually owned and cannot be partitioned among

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individuals. Irrigators have the incentive to only consider their own profit when deciding on the best water consumption and to ignore the effect of water withdrawal on the entire water stock. In this situation, the aquifer will be depleted faster than the economically efficient rate (Shah, Zilberman, and Chakravorty, 1995). Policy intervention is needed to solve or alleviate the common pool problem of groundwater use.

A common conservation practice implemented is to improve irrigation efficiency. Irrigation efficiency is the ratio of effective water use to gross irrigation. Effective water use, also called consumptive use, is the amount of water beneficially used by crops; gross irrigation is the amount of water diverted from the water source. In Kansas, eligible producers can receive cost-share assistance for conversion from flood irrigation systems to sprinklers and from low-efficiency center pivot sprinklers to high-efficiency ones. Although more efficient irrigation technologies are suggested to be water-saving, there is substantial controversy in the literature on the conservation effects of efficiency improvements (Huffaker and Whittlesey, 1995, 2003; Peterson and Ding, 2005; Ward and Pulido-Velazquez, 2008). More efficient irrigation technologies reduce the cost of effective water, and profit-maximizing producers will respond to this cost change by increasing effective water use. Because the amount of gross irrigation is the ratio of effective water and the efficiency rate, whether it increases or decreases after the efficiency improvement is undetermined. Additionally, increased efficiency might change producers' decisions on irrigated acreage and/or cropping systems and thus could cause more water to be diverted as a result of expansions at the extensive margin (Moore, Gollehon, and Carey, 1994). Therefore, the water-conserving effect of more efficient irrigation technologies remains an empirical question.

Another frequently discussed conservation practice is to convert irrigated crop production to dryland crop production. Incentive payments are provided to participating producers for temporarily or permanently retiring their consumptive water rights. Wheeler et al. (2008) compared the economic efficiency of short-term and long-term water rights buyout policies. The difficulty with these policies is to determine an appropriate payment rate in the absence of an active water market. Because producers are diversified in their cropping systems, production practices, and hydrologic conditions, the compensation payment they are willing to accept for giving up irrigation could vary significantly. Changes in crop prices may also affect the effectiveness of this policy. High crop prices make irrigated crop production more profitable and therefore reduce producers' willingness to retire or temporarily suspend their water rights.

Beginning with the 2002 Farm Bill, the Ground and Surface Water Conservation (GSWC) program was added to the Environmental Quality Incentives Program. It is a voluntary program, which provides cost-share assistance and incentive payments to producers who wish to implement water conservation practices. With millions of dollars spent each year, relatively little is known about the performance of the GSWC program. It is of particular interest for policymakers and stakeholders to know how much water could be saved through the subsidized conservation programs and how effective these programs are in saving water.

The objective of this article is to analyze and quantify the effectiveness of cost-share and incentive payment programs in terms of how much water can be saved for each dollar of government payment. We intend to estimate the potential water-saving effect when these policies are applied to a group of irrigators with different hydrologic conditions. To fulfill this goal, we constructed a dynamic optimization model in which a representative producer decides on the optimal irrigation technology, crop selection, and water withdrawal. The baseline results are solved with no policy intervention; we then calculate and compare the potential water saving and the cost-effectiveness of government payments under alternative policy scenarios.

Model Development

Many studies have analyzed the determinants of technology choices and irrigation water use (e.g., Caswell and Zilberman, 1986; Buller and Williams, 1990; Negri and Brooks, 1990). Previous findings suggest that determinants include but are not limited to commodity prices, energy prices, pump lift, and well capacity. Irrigation technology selection could affect the amount of water use as well. Because the investment in irrigation technology is a long-run decision, which has dynamic effects on future crop selection and water withdrawals, decisions by the irrigator should maximize the sum of current and discounted future profits.

To model this dynamic optimization problem, Ding (2005) constructed a nested framework involving three optimization problems. First is the optimal choice of irrigation technology, which requires the irrigator to weigh upfront investment costs against future benefits, in which the benefits in future periods are not constant as a result of the declining water level of the aquifer. The Bellman equation (Bellman, 1957) of the dynamic optimization problem is written as

$$V(s,m) = \underset{x=0.1,2}{Max}\{\Pi(s,x) - K(m,x) + \beta V(s',m')\} \tag{1}$$

where x denotes the discrete choice variable that equals 0 if the irrigator chooses to stay with the flood system, 1 if he or she chooses the center pivot sprinkler method, and 2 if he or she converts to nonirrigated production. The parameter β is the discount factor. The function $V(.)$ represents the maximized (discounted) total profits that the irrigator could obtain given the current state (s, m). The state variables include the saturated thickness of the aquifer (s) and the age of the existing irrigation system (m). As the saturated thickness declines, the depth to the water table increases, which increases pumping costs; meanwhile, well capacity decreases, which limits the water supply. Therefore, irrigators with land associated with an aquifer of lower saturated thickness might have a greater incentive to adopt more efficient irrigation technologies. However, when the level of saturated thickness is very low, irrigation could become unprofitable, and the producer would stop irrigation and switch to dryland production. A common usable lifetime of an irrigation system is 15–20 years. Based on previous research in western Kansas (DeLano and Williams, 1997), we assume the usable lifetime is 20 years for both the flood and center pivot systems with no salvage value. An old system must be completely replaced at the age of 20 years or else irrigation must be abandoned. Irrigators with older systems are expected to be more likely to adopt new and more advanced irrigation systems.

$K(m, x)$ is the cost of the initial investment, which depends on the choice of irrigation system and the age of the existing system.

$$\begin{aligned} K(m,x) = {} & I(m < 20)(I(x = 1)K_1) \\ & + I(m = 20)[I(x = 0)K_0 \\ & + I(x = 1)K_1] \end{aligned} \tag{2}$$

where $I(.)$ is a binary indicator function that equals 1 if its argument is true and zero otherwise. K_0 and K_1 are the initial investment costs for the flood and center pivot systems, respectively.

The state variables s' and m' in Equation (1) are the expected values of saturated thickness and age of the irrigation system for the next period based on current state variables and decisions. Letting z denote the water table decline rate, the saturated thickness of the aquifer decreases by z for the next period (i.e., $s' = s - z$). Because the aquifer is a common pool resource, we assume that an individual irrigator places no value on any water preserved for future periods because he or she would reason that all but a negligible share of the benefit would go to other users (Gisser and Sanchez, 1980). In this case, we set z to be a constant value. The age of the existing system, m, increases by 1 year for the next period: $m' = m + 1$.

Given the irrigation technology selected by solving the optimization problem in Equation (1), the second step for the profit-maximizing irrigator is to make the optimal crop choice. In Equation (1), $\Pi(.)$ is the maximized return to land and irrigation capital for a given irrigation technology. A standard parcel in Kansas, and throughout the High Plains, is a 160-arce square field, which is usually irrigated from a single well. Assume the flood system can irrigate the entire 160-acre field, whereas the center pivot system only can irrigate a 126-acre circle within the field with dryland production on the four corners. So, we write

$$\begin{aligned} \Pi = {} & 160\pi_0^* I(x = 0) + (126\pi_1^* + 34\pi_2^*) I(x = 1) \\ & + 160\pi_2^* I(x = 2) \end{aligned} \tag{3}$$

where π_0^*, π_1^*, and π_2^* are the maximized profits per acre under the flood irrigation system, the center pivot irrigation system, and dryland production, respectively. We observe that in many parts of western Kansas, farmers irrigate only part of their irrigatable area and leave the rest for dryland production. As water availability diminishes, farmers may adjust not only by switching crops, but also by reducing the irrigated area. To allow for this possibility, the model selects the optimal share of irrigatable area to be watered as well as the optimal crop for each irrigation technology. Assume there are J alternative crop choices available, the irrigator makes the crop choice by solving the subsequent problem:

$$(4)\qquad \pi_x^* = \underset{d,\rho_j}{Max}\left\{d\sum_{j=1}^{J}\rho_j\pi_{xj}^* + (1-d)\pi_2^*\right\}$$

where π_{xj}^* is the maximized profit under the combination of technology x and crop choice j, d is the share of land irrigated, and ρ_j is the share of irrigated land planted to crop j.

The final step for the irrigator is to solve for the optimal irrigation water use (w_{xj}^*) to maximize the profit under the selected irrigation technology and crop (i.e., π_{xj}^*). The maximization problem is written as

$$(5)\qquad \begin{aligned}\pi_{xj}^* = \underset{w_{xj}}{Max}\,&\{p_jy_j - r(u,l)w_{xj} - I_{xj}\\ &+ \lambda_j(\bar{w} - w_{xj})\}\end{aligned}$$

where p_j and y_j are the price and yield of crop j, respectively; r is the marginal pumping costs, which is a function of energy price (u) and pump lift (l); I_{xj} is the production cost other than pumping costs (including the cost of seeds, fertilizer, machinery, labor, etc.); and $\bar{w}$ is the water supply constrained by well capacity.[1] For yield, assume that crop yield is a function of effective water (i.e., the water used by the crop), denoted e, and that effective water is the product of water applied through the irrigation system (w) and irrigation efficiency (h_x).

$$(6)\qquad y_j = f_j(e) = f_j(h_xw)$$

The three-staged optimization problem specified in Equations (1), (4), and (5) can be solved by backward induction. First, the optimal quantities of irrigation water are selected for all combinations of crop choices and irrigation technologies; second, the crop choices are compared and the most profitable one is determined under a certain irrigation technology; and finally, the technology choice is made by comparing the sum of current and discounted future profits across alternative irrigation technologies. Numerically, the dynamic optimization problem specified in Equation (1) is solved by using a computational package in Matlab (MATLAB 6.5, 2002) developed by Miranda and Fackler (2002).

After reviewing how an irrigator optimally chooses the irrigation technology without the assistance of government programs, we now return to our original question: when the cost-share assistance and incentive payments are available, how would the irrigator respond? Assume that the starting value of the saturated thickness is s_0 and the age of the initial system is m_0. The profit associated with option one (do not participate in any government program and stay with the existing flood irrigation system) is $V_0 = V(x = 0, s_0, m_0)$; the profit associated with option two (share costs with the government and replace the existing flood irrigation system with a new center pivot irrigation system) is $V_1 = V(x = 1, s_0, 0) + \theta K_1$, where θ is the cost-share rate; the profit associated with option three (accept the government incentive payment and retire the water right during the contract period[2]) is

$$V_2 = \sum_{t=0}^{T-1}\beta^t(160\pi_2^*) + \beta^TV(x=2,\, s_{+T},\, m_{+T}) + C,$$

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[1] For example, if the well capacity is 900 gallons per minute (GPM), and the water pump runs for 2400 hours in a season, then no more than 4772.7 acre-inches of water can be pumped. This implies a maximum application rate of 30 inches per acre for a 160-arce parcel, or 38 inches per acre for a 126-arce circle. Based on personal communication with Hecox (2003), the well capacity in this study is assumed to be directly related to the saturated thickness by the following equation: $GPM = \frac{(k)(s)(s-10)}{267} * 0.6$, where k is the hydraulic conductivity.

[2] Assume it is a T-year contract, and the irrigator is free to resume irrigated production or stay with dryland production when the contract ends.

where s_{+T} and m_{+T} are the expected values of saturated thickness and the irrigation system age in 10 years, respectively, and C is the compensation payment for retiring the water right. The irrigator would compare the profits associated with alternative options and choose the most profitable one:

$$(7) \qquad Max(V_0, V_1, V_2)$$

After determining the irrigator's technology choice, we can calculate the corresponding crop choice and water use the planning horizon and compare the cumulative water use under alternative policy scenarios.

Let N denote the number of producers eligible for government cost-share assistance and incentive payments in the targeted program area. Assume that N_1 producers accept cost-share assistance (θK_1) and convert to the center pivot irrigation system; that another N_2 producers accept the government incentive payment (C) and convert to the dryland production; and that the rest of the $N_0 = N - N_1 - N_2$ producers do not participate in any government program and stay with the existing flood irrigation system. The total payments from the government are

$$(8) \qquad \Lambda = N_1(\theta K_1) + N_2 C$$

and the total water saved during T years is

$$(9) \qquad W = \sum_{n=1}^{N_1}\sum_{t=1}^{T}(w^*_{0nt} - w^*_{1nt}) + \sum_{n=N_1+1}^{N_1+N_2}\sum_{t=1}^{T}(w^*_{0nt})$$

where w^*_{xnt} is the optimal water use under technology x for irrigator n at time t. The coefficient of cost-effectiveness (CE), in terms of the amount of water saved per dollar, is calculated as:

$$(10) \qquad CE = \frac{W}{\Lambda}$$

Model Parameters

The model requires several economic, production, and hydrologic parameters, including crop prices, pumping costs, irrigation capital requirements, production costs, crop response functions, saturated thickness of the aquifer, and decline rate of the aquifer. Estimates of these parameters are based on common crop production practices, hydrologic characteristics, and weather conditions specific to irrigators in the Kansas High Plains. Table 1 summarizes the major model parameters used in this study.

The Crop Production Functions

For this study, assume corn and sorghum are the two alternative crop choices for irrigators. Both are major irrigated crops in the Kansas High Plains. Corn is the dominant irrigated crop, planted on over 50% of all irrigated acreage. Sorghum is a water-extensive crop and is usually regarded as a replacement for corn (a water-intensive crop) when there are limited water supplies. Assume the production function in Equation (6) takes a quadratic functional form:

$$(11) \qquad y = \alpha_0 + \alpha_1 e + \alpha_2 e^2$$

This function is estimated for corn and sorghum, respectively, using the data generated by the Crop Water Allocator Software (2004). This program was designed by Kansas State University Research and Extension to simulate irrigated

Table 1. Values of Model Parameters Used in Simulations

Parameters	Values
Coefficients of production function	
Corn (bushel)	
α_0	33.4525
α_1	16.0891
α_2	–0.4023
Grain sorghum (bushel)	
α_0	42.6486
α_1	7.1289
α_2	–0.1963
Nonenergy irrigation cost ($/acre)	
Corn	58.97
Grain sorghum	37.53
Nonwater production costs ($/acre)	
Corn	426.93
Grain sorghum	259.31
Initial investment cost of irrigation system ($/parcel)	
Flood	5,280
Center pivot	59,976
Corn price ($/bushel)	4.39
Grain sorghum price ($/bushel)	3.93
Natural gas price ($/mcf)	12.13

crop yields under growth conditions typical of western Kansas. The default relationships between yield and irrigation built into the program are based on the Kansas Water Budget Model developed by Stone et al. (1995), which was in turn calibrated to yield data obtained at field trials in western Kansas. The parameters (αs) were estimated using ordinary least squares and the results are reported in Table 1.

Effective water (e) is the product of the applied water (w) and the irrigation efficiency (h). In western Kansas, water application efficiency with the flood system is generally in the range of 50–75% depending on the field characteristics, whereas with the center pivot irrigation system, it is in the range of 75–95%. For this study, we set the irrigation efficiency to be 60 and 90% for the flood irrigation and center pivot irrigation systems, respectively.

Prices and Costs

Data on crop prices and production costs are 4-year (2007–2010) averages from Kansas State University Extension crop budgets in those years (see Dumler et al., 2010a, 2010b). The average prices of corn and grain sorghum are \$4.39/bu and \$3.93/bu, respectively. The profit from dryland crop production, for simplicity, is set to be the cash rent for dryland crops in the Extension budgets; the 4-year average value is \$32/acre. Nonwater production costs include expenses for seed, herbicide, insecticide, fertilizer, crop consulting, machinery, and interest. Nonenergy irrigation costs include repairs and maintenance costs as well as labor cost. These costs are calculated for each crop choice. Irrigation system investment costs are taken from Dumler, O'Brien, and Rogers (2007). The initial investment cost of the flood irrigation system is much lower than that of the center pivot irrigation system. The cost is \$5,280 (K_0) for the flood system and \$59,976 (K_1) for the center pivot system.

The pumping cost (r) is assumed to be a function of fuel price (u) and pump lift (l) set $r = u\delta l$, where δ is the energy required to lift one unit of water one unit of distance. Because natural gas is the most popular fuel used in western Kansas for pumping water, its price is used to represent the fuel price in the model. The 4-year (2007–2010) average price of natural gas is calculated based on data from the Department of Energy/Energy Information Administration. Assuming that the pump plant is 75% efficient (this is distinct from the water application efficiency of the delivery system), 0.000155 million cubic feet (mcf) of natural gas is required to lift 1 acre-inch of water 1 inch (i.e., $\delta = 0.000155$) (Rogers and Alam, 1999).

Hydrologic Characteristics

The pump lift is the sum of the depth to the water table (*dtw*, measured in feet) and the vertical lift equivalent of the pressure of the water at the exit from the delivery system (measured in pounds per square inch [psi]). The water pressure is converted to feet by a conversion factor of 2.31 feet per psi. Assume that the pressure is 5 psi for the flood system and 20 psi for the center pivot system (Williams et al., 1997). The depth to the water table is the distance from the land surface to the groundwater level. As the level of saturated thickness decreases, the pump lift increases correspondingly.

The decline rate of the water table would be affected by total groundwater withdrawal. However, because of the common pool problem, an individual irrigator would assume the decline rate to be exogenous to his or her water extraction. We assume that irrigators use historical records to forecast the future water table decline rate. For this study, we use a constant decline rate of 6 inches per year, which is the average decline rate of the Ogallala aquifer in Kansas during the 1990s (Kansas Geological Survey, 2000).

Results

The optimization model was used to simulate irrigators' decisions under different policy scenarios and under a large set of starting values of the state variables: saturated thickness and the age of the existing flood irrigation system. To illustrate the nature of the model's outputs in each execution, consider the optimal results with no policy interventions for an irrigator with a 10-year old flood irrigation system. If the starting value of saturated thickness of the aquifer is greater than 90 feet, the model predicts this irrigator will continue using flood irrigation until the saturated thickness drops to 90 feet, at which point he or she will immediately convert to the more efficient center pivot irrigation system. If the initial saturated thickness of the aquifer is between 59 and 90 feet, the gain from the irrigation efficiency improvement is diminished by the limited well capacity. In this case, the flood system will continue to be used until irrigation is abandoned, because the gains from the conversion are not enough to cover the initial investment cost of the center pivot system. In either of these cases, irrigation will continue until saturated thickness drops to under 30 feet; at this point, irrigation becomes too costly and the irrigator should convert to dryland crop production. In this analysis, we describe how the change of aquifer-saturated thickness affects a representative irrigator's choice when the starting value of the flood irrigation system's age equals 10 years (i.e., $m_0 = 10$). As the age of the existing system increases and nears its usable life of 20 years, irrigators would be more willing to invest in the more efficient center pivot irrigation systems.

This study is intended to investigate the effect of water conservation programs when they are applied to a group of irrigators with different hydrologic conditions. Irrigators with land on aquifers with different saturated thicknesses would respond differently to alternative conservation programs and would require different cost-share rates to make the conversion to more efficient irrigation technologies or incentive payments to convert to dryland crop production. However, policymakers usually have no clear information on each irrigator's well or they might be unable to differentiate the irrigators as a result of political reasons. Regardless of the reason, existing programs usually offer a fixed cost-share or incentive rate for which all irrigators are eligible. To understand how different producers respond to these uniform instruments, we model the optimal responses for a group of irrigators with initial saturated thickness following a normal distribution.

Assume that there are 100 eligible irrigators in one of the program target areas, i.e., n = 100. Most irrigation wells in western Kansas have a water level ranging from 70 to 130 feet, averaging 100 feet. Therefore, we assume that the saturated thickness for each irrigator is a random draw from a normal distribution with a mean of 100 and a variance of 100. Similarly, the age of the existing irrigation system is a (uniformly distributed) random number drawn from one to 20. For each irrigator, we first determine whether he or she will enroll in any conservation program, and then, if he or she will enroll, how much water will be saved during a 10-year contract period. The results from each irrigator are summarized to obtain the enrollment rate, total government payments, and total water saved. These values are then used to calculate the cost-effectiveness as specified in Equation (10). The cost-effectiveness we calculated is interpreted as the amount of groundwater saved during the 10-year period for $1 spent today. To even out the variability of random draws, this procedure is repeated 100 times, and the final reported results are the average values from the 100 iterations. The baseline results are solved under no policy intervention and then compared

Table 2. Cost-Effectiveness of Alternative Conservation Programs under Different Cost-Share Rates and Incentive Payment Levels

		Cost-Share Rates					
		0%	10%	20%	30%	40%	50%
Incentive payments ($)	0	0.000	0.073	0.095	0.096	0.088	0.081
	20,000	0.000	0.073	0.095	0.096	0.088	0.081
	40,000	0.000	0.073	0.095	0.096	0.088	0.081
	60,000	0.000	0.073	0.095	0.096	0.088	0.081
	80,000	0.001	0.073	0.095	0.096	0.088	0.081
	100,000	0.001	0.073	0.095	0.096	0.088	0.081

Table 3. Total Water Savings (acre-inches) of Alternative Conservation Programs under Different Cost-Share Rates and Incentive Payment Levels

		Cost-Share Rates					
		0%	10%	20%	30%	40%	50%
Incentive payments ($)	0	0	11,293	37,759	67,327	90,923	111,741
	20,000	0	11,293	37,759	67,327	90,923	111,741
	40,000	0	11,293	37,759	67,327	90,923	111,741
	60,000	0	11,293	37,759	67,327	90,923	111,741
	80,000	114	11,407	37,759	67,327	90,923	111,741
	100,000	114	11,407	37,873	67,440	91,037	111,855

with the simulated results under alternative cost-share rates and incentive payment levels.

The baseline results indicate that, with no policy intervention, the 100 irrigators would withdraw a total of 3,517,026 acre-inches (293,086 acre-feet) of water during the 10-year period. In Tables 2, 3, and 4, we report the cost-effectiveness, total water saved, and total government expenditures under different cost-share rates and incentive payment levels. For example, the first row in Table 2 presents the values of the cost-effectiveness when the incentive payment equals zero and the cost-share rate increases from 0 to 50%. Without incentive payment, the highest cost-effectiveness (0.096) is reached when the cost-share rate is set at 30%, and the resulted water saving is 67,327 acre-inches, which is approximately 2% of the baseline water withdrawal. The first column in Table 2 reports the values of cost-effectiveness when the cost-share rate equals zero and the incentive payment ranges from $0 to $100,000. The incentive payment program seems to be ineffective. Few irrigators are willing to accept the payment and temporarily retire their water rights by switching to dryland production even when the incentive payment is as high as $100,000. This is partly the result of the high prevailing grain prices, which makes irrigated crop production more profitable.

Suppose prices of corn and grain sorghum are reduced by 10% (Table 5). The incentive payment program then becomes more effective than the cost-share program. The highest cost-effectiveness (0.187) is reached when the incentive payment is $100,000 and the cost-share rate is zero. If prices of corn and grain sorghum are reduced by 20% (Table 6), even higher cost-effectiveness (0.559) will be achieved with a lower level of incentive payment ($40,000).

In this analysis, irrigators' saturated thickness is assumed to follow a normal distribution with the mean of 100 feet. In the real world, program areas may have an average saturated thickness greater or lower than this value. It is important to know how these changes might affect the cost-effectiveness of alternative conservation programs. Consider a group of 100 irrigators with an initial saturated thickness following a normal distribution with a mean of 90 and a variance of 100. Following the same procedure, we simulate the total water-saving and government payments under alternative

Table 4. Total Government Expenditures ($) of Alternative Conservation Programs under Different Cost-Share Rates and Incentive Payment Levels

		Cost-Share Rates					
		0%	10%	20%	30%	40%	50%
Incentive payments ($)	0	0	154,018	396,441	700,820	1,032,787	1,390,244
	20,000	0	154,018	396,441	700,820	1,032,787	1,390,244
	40,000	0	154,018	396,441	700,820	1,032,787	1,390,244
	60,000	0	154,018	396,441	700,820	1,032,787	1,390,244
	80,000	800	154,758	396,441	700,820	1,032,787	1,390,244
	100,000	1,000	154,958	397,321	701,640	1,033,547	1,390,944

Table 5. Cost-Effectiveness of Alternative Conservation Programs under Different Cost-Share Rates and Incentive Payment Levels When Crop Prices Decrease by 10%

		Cost-Share Rates					
		0%	10%	20%	30%	40%	50%
Incentive payments ($)	0	0.000	0.099	0.100	0.101	0.100	0.096
	20,000	0.000	0.099	0.100	0.101	0.100	0.096
	40,000	0.003	0.100	0.100	0.101	0.100	0.096
	60,000	0.025	0.104	0.101	0.101	0.100	0.096
	80,000	0.108	0.122	0.108	0.104	0.101	0.097
	100,000	0.187	0.154	0.124	0.111	0.105	0.099

policy scenarios. Table 7 reports the values of cost-effectiveness. The incentive payment program is now more effective than the cost-share program when facing irrigators with shallower saturated thickness. The highest cost-effectiveness (0.065) is reached when the incentive payment is $100,000 and the cost-share rate is zero. This result is consistent with our expectation that irrigators with poorer hydrologic conditions expect low returns from continuing irrigation and therefore would be more likely to accept the incentive payment for the conversion to dryland production.

In a similar analysis, we calculate the cost-effectiveness of alternative policies assuming they are available to a group of irrigators with an average aquifer saturated thickness of 110 feet. As shown by the results in Table 8, the incentive payment program is now completely ineffective because no one is willing to participate, whereas the cost-share program becomes more effective than before. The highest cost-effectiveness (0.148) is reached when the cost-share rate is set at 20% and the incentive payment is zero.

In sum, many irrigators in thin areas of the aquifer will find it unprofitable to adopt more efficient irrigation technologies without policy intervention. However, with cost-share assistance, these producers might be able to afford the cost-efficiency improvements and stay in irrigation longer and eventually pump more water out of the aquifer. Therefore, a cost-share program might not be a good policy choice in such areas. The incentive payment program and the cost-share program should be used to target different irrigator groups. In areas with low saturated thickness, the incentive payment program is more effective; whereas in areas with relatively higher water availability, the cost-share program could be a better choice. We also note that the coexistence of these two programs might either increase or decrease the cost-effectiveness of water savings. In Table 7, when the incentive payment equals $80,000, increasing the cost-share rate from 0% to 10% improves the cost-effectiveness from 0.027 to 0.042. However, when the incentive payment equals $100,000, the same increase in the cost-share rate reduces the cost-effectiveness from 0.065 to 0.049.

Table 6. Cost-Effectiveness of Alternative Conservation Programs under Different Cost-Share Rates and Incentive Payment Levels When Crop Prices Decrease by 20%

		Cost-Share Rates					
		0%	10%	20%	30%	40%	50%
Incentive payments ($)	0	0.000	0.000	0.000	0.023	0.056	0.073
	20,000	0.364	0.364	0.364	0.058	0.068	0.079
	40,000	0.559	0.559	0.559	0.383	0.155	0.106
	60,000	0.475	0.475	0.475	0.475	0.475	0.475
	80,000	0.411	0.411	0.411	0.411	0.411	0.411
	100,000	0.354	0.354	0.354	0.354	0.354	0.354

Table 7. Cost-Effectiveness of Alternative Conservation Programs under Different Cost-Share Rates and Incentive Payment Levels When the Average Aquifer Saturated Thickness Equals 90 Feet

		Cost-Share Rates					
		0%	10%	20%	30%	40%	50%
Incentive payments ($)	0	0.000	0.040	0.050	0.048	0.044	0.039
	20,000	0.000	0.040	0.050	0.048	0.044	0.039
	40,000	0.000	0.040	0.050	0.048	0.044	0.039
	60,000	0.005	0.040	0.050	0.048	0.044	0.039
	80,000	0.027	0.042	0.051	0.048	0.044	0.039
	100,000	0.065	0.049	0.053	0.049	0.045	0.040

Conclusions

Irrigated crop production in western Kansas depends largely on groundwater derived from the Ogallala aquifer. However, excessive water withdrawals and low recharge rates have led to rapid decline of the water table and the near exhaustion of the aquifer in some areas. Many policy alternatives for conserving irrigation water have been proposed and some of them have already been put in practice. This study has investigated two commonly discussed policies: 1) a cost-share program for improving irrigation efficiency (e.g., shifting from flood to central pivot irrigation methods); and 2) an incentive payment program for temporarily retiring water rights (e.g., shifting from flood irrigation to dryland production). The conservation effects of more efficient technologies are theoretically undetermined, because irrigators may respond to the higher irrigation efficiency by increasing net irrigation, irrigating more acres, or even planting more water-intensive crops. Therefore, to evaluate the effectiveness of the cost-share program empirically, we developed a dynamic model to project a representative irrigator's water use, crop selection, and choice of irrigation technology under typical conditions of the Kansas High Plains located within the Ogallala aquifer. Dryland production is modeled as an irrigation technology choice alongside the flood irrigation system and the center pivot irrigation system, allowing us to evaluate the effectiveness of the incentive payment program within the same framework.

The results suggest that both policies can be effective in reducing irrigation water use, although their effectiveness is small and limited under certain conditions. High prevailing crop prices greatly reduce irrigators' incentive to give up irrigation and therefore cause low enrollment and ineffectiveness of the incentive payment program. The cost-share program is less effective than the incentive payment program in areas with low saturated thickness, whereas in areas

Table 8. Cost-Effectiveness of Alternative Conservation Programs under Different Cost-Share Rates and Incentive Payment Levels When the Average Aquifer Saturated Thickness Equals 110 Feet

		Cost-Share Rates					
		0%	10%	20%	30%	40%	50%
Incentive payments ($)	0	0.000	0.119	0.148	0.141	0.127	0.112
	20,000	0.000	0.119	0.148	0.141	0.127	0.112
	40,000	0.000	0.119	0.148	0.141	0.127	0.112
	60,000	0.000	0.119	0.148	0.141	0.127	0.112
	80,000	0.000	0.119	0.148	0.141	0.127	0.112
	100,000	0.000	0.119	0.148	0.141	0.127	0.112

with relatively thick saturated depths, the cost-share program could be a better choice. The results suggest that the overall water-saving effectiveness can be improved when different policy tools are considered under different conditions. Future research can explore optimal ways of targeting policies by restricting eligibility depending on producer types.

Our conclusions are derived from the simulated results based on the economic conditions, production practices, and hydrologic characteristics typical of the Kansas High Plains. Our findings are important for policymakers in the evaluation of effectiveness of alternative water-conserving policies while also providing valuable information for designing future programs. One limitation of the model is that we assume prices, investment costs, and hydroclimatic variables to be constant or to change at a constant rate over time. Although including stochastic variables into the model could add realism, the computation effort required to solve a dynamic model grows exponentially with the number of state variables, and this problem is compounded if the added state variables are stochastic. In the future, we expect to predict and compare different policy results under alternative price scenarios and changing hydroclimatic conditions. By changing the values of model parameters, our analyses can also be applied to other regions for analyzing similar problems.

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