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Adoption of More Technically Efficient Irrigation Systems as a Drought Response

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ABSTRACT *Adoption of technically efficient irrigation systems can mitigate the effects of drought by allowing irrigators to maintain water consumption with reduced applications. This paper uses survey data from the worst drought in Colorado's history to examine how drought conditions affect the choice of irrigation system by irrigators. Results indicate that drought conditions did significantly increase the percentage of farms using more efficient sprinkler systems relative to gravity systems. The key factors affecting the decision were land tenure, farm scale and available water supply, suggesting that those enterprises with the most owned land, the highest number of acres and the most reliable water supplies are most likely to invest in more efficient irrigation systems during severe droughts.*

Introduction

In 2002 Colorado experienced the worst drought in the state's history. Water rights dated 1865 and 1881 placed calls on the South Platte River—the most senior calls placed on the river in over a generation—and the Rio Grande very nearly ceased to flow (Hall, 2002). The severity of this drought cannot be overstated. These conditions were rated 'exceptional' by the US Drought Monitor and were the most severe drought experienced in the region since the 'Dust Bowl' (National Oceanic Atmospheric Administration, 2002; Tronstad & Feuz, 2002). Indeed, based on studies of tree rings and archaeological evidence from aboriginal cultures, the Colorado drought was arguably the worst in recorded history (Pielke *et al*., 2003).

Agriculture is the dominant user of water in the state, so the effects of the drought hit this sector of the economy especially hard. The state's most widely planted crop by acreage, winter wheat, saw production fall by nearly 30 million bu. (817 000 tonnes) between 2001 and 2002, a reduction of almost 60% (National Agricultural Statistics Service, 2003a). Total livestock numbers in the state fell by almost 14% from 2002 to 2003, a blow that was of great concern since livestock accounts for nearly 60% of the state's agricultural production by value (National Agricultural Statistics Service, 2003b).

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While the direct economic impact of the drought is certainly of interest, an important question arises with important policy implications for irrigated agriculture: that is, to understand how irrigators responded to this drought, and what changes were made in production practices to alleviate the effects of this and future droughts.

Irrigators can respond to drought in a variety of ways. In the short term, they can reduce water applications, fallow acreage or change crops. With their eye on a longer horizon, they can also adopt different irrigation systems. This latter response is of great concern. While changes in irrigation technology can allow producers to continue production on lower levels of water applications, changes in return flows stemming from changes in irrigation technology can have profound impacts on both downstream flows and water quality. As a result, while more technically efficient irrigation systems can potentially help individual farms survive droughts, the regional effects may or may not be helpful. Using farm-level survey data from Colorado irrigators, this research assesses if irrigators in Colorado adopted new irrigation systems in response to the 2002 drought, how prevalent this response was, what factors influenced this decision and what the potential implications are for overall water supplies in the state as a result of any observed changes in irrigation technology.

Background

Adoption of more technically efficient irrigation systems may be a way to facilitate production during severe droughts by maintaining consumption with reduced applications. More technically efficient irrigation systems, such as low-pressure sprinkler or drip systems, transmit a higher proportion of applied water to the root zones of crops. This allows a higher level of water consumption for crops at a given level of water application, and can allow an irrigator to reduce irrigation application rates while still meeting the consumptive demands of the crops.

Improvements in irrigation efficiency frequently correspond to moderate yield improvements (Dinar & Zilberman, 1991) and can also reduce production costs and decrease salinization (Wichelns, 1991). Both yield effects and cost reductions can improve on-farm profits and should promote adoption. However, not all irrigators will be able to take advantage of these alternative technologies or management practices. On-farm variations in land attributes, historical cropping patterns and water costs may make changes in irrigation systems that are generally more profitable less so in specific cases (Green *et al.*, 1996; Green & Sunding, 1997; Schuck & Green, 2001).

The existing irrigation technology adoption literature is both extensive and well developed (see Caswell & Zilberman, 1985; Lichtenberg, 1989; Dinar & Yaron, 1990; Negri & Brooks, 1990; Dinar & Zilberman, 1991; Shrestha & Gopalakrishnan, 1993; Green *et al.*, 1996; Green & Sunding, 1997; Schuck & Green, 2001). In general, higher water costs have been found to lead to adoption of more technically efficient irrigation systems, as has lower-quality water. However, the existing literature on the adoption of improved irrigation technology tends to emphasize price as an indicator of scarcity rather than actual measures of physical scarcity. Additionally, most of the cited literature focuses on the unique irrigation conditions of Israel's Negev or California's San Joaquin Valley.

While these areas are important areas of production, they are not necessarily representative of other irrigated areas. In particular, their institutional settings are very different from Colorado. Specifically, while the San Joaquin Valley receives the majority of its water through the US Bureau of Reclamation (USBR) via service contracts between regional irrigation districts and irrigators, most water in Colorado is privately held and distributed through either direct diversions or private mutual share ditch companies (Frasier *et al.*, 1999). As a result, unlike California, where irrigators typically pay a volumetric price to the USBR or an intermediate water provider to obtain water, Colorado irrigators already hold the right to the water, either individually or collectively, and do not need to pay a volumetric price to acquire water. Rather, they pay a fraction of the costs of the delivery infrastructure and these costs are typically not volumetric. Consequently, while existing irrigation technology literature from California emphasizes the role of volumetric price in determining irrigation technology choices, this is not a variable that Colorado irrigators face.

What this means is existing irrigation technology adoption literature reflects an institutional structure and irrigation environment that are very different from Colorado and other parts of the western USA. Results from these regions may not be compatible with the Colorado experience, particularly during droughts. The most important difference between California and Colorado relates to water price. Since most irrigation water in Colorado is privately held, few irrigators face a discernible marginal water price. In the absence of a known marginal price, existing models of irrigation technology adoption do not accurately describe Colorado. This divergence between publicly held 'government' water and privately owned water can lead to different incentives for irrigators in Colorado than are seen in other regions. Without a marginal price to observe as a measure of scarcity during droughts, it is necessary to use physical measures of water supply in their place. This research examines how irrigators in Colorado adopted improved irrigation technology in response to reduced on-farm water supplies during the 2002 drought, extending existing irrigation technology models to better reflect the institutional environment of Colorado and other settings where irrigators do not face a price for water.

The other critical difference between Colorado and other irrigated areas relates to farm structure. Many of the irrigation technology adoption models from California describe a single crop grown under a single irrigation system (see Green *et al.*, 1996; Green & Sunding, 1997; Schuck & Green, 2001). Irrigated farms in Colorado tend to grow several crops under a variety of adjacent irrigation systems. Consequently, it is possible to observe several different types of irrigation systems all being operated simultaneously on the same farm by the same manager. During a drought, an irrigator will have to evaluate the effectiveness of the entire farm's irrigation infrastructure, choosing to upgrade some portions and downgrade others depending upon the relative cost of changes to each different system. In this context, how irrigators managed their overall mix of irrigation systems observed on the farm matters more than how drought influenced adoption rates for a given system. It is therefore necessary to model irrigation technology adoption during a drought as a proportional mix of systems across the farm, not simply as a single choice.

The combination of these two differences—one in water delivery institutions, one in the nature of the farms analysed—means that existing literature on adoption of improved irrigation systems may not accurately reflect experiences in Colorado. Given the unprecedented severity of the 2002 drought in Colorado, developing irrigation technology adoption models adapted to the state is essential in assessing the full economic impacts of the drought on the state. This research uses surveys of irrigators from the 2002 drought to examine whether or not Colorado irrigators adopted more technically efficient irrigation systems in response to this extreme drought event. It does so in a Colorado-specific context that substitutes physical measures of scarcity for water prices and evaluates the mix of irrigation systems across a single farm rather than as a single crop/field choice. This paper proceeds by first developing a theoretical model of irrigation technology adoption in Colorado, and then evaluates this model using survey data taken during the 2002 drought in Colorado.

Irrigation Technology Adoption Model

One of the more fundamental problems in crop water demand is that water use in agriculture tends to be highly inelastic (Nieswiadomy, 1988; Ogg & Gollehon, 1989). Given this, changes in water use must focus at the extensive rather than the intensive margin. One of the primary means of changing water use at the extensive margin is through adjusting the efficiency of irrigation systems. The question then is simply a matter of identifying how and why irrigators choose the irrigation systems they do.

While higher water costs are associated with adopting more technically efficient irrigation systems, more recent work by Carey & Zilberman (2002) suggests that the hurdle rates for adopting more efficient systems can be quite high and are often dependent upon major external events such as drought.

The basic irrigation technology adoption problem is well established, and most research follows the model first put forward by Caswell & Zilberman (1986). Following Caswell & Zilberman (1986), the profit-maximizing irrigator will choose the *j*th irrigation system over the competing *k*th irrigation system if the *j*th system is perceived as being more profitable than the *k*th system. If π_j are the profits under the *j*th system and π_k are the profits under the *k*th system, then the condition for the adoption of the *j*th system over the *k*th system is simply:

$$\pi_j > \pi_k \tag{1}$$

Profits are determined by the revenues and costs from production under a given irrigation system. For each farm, a farmer will maximize profits by choosing a vector of acreage allocations (l) and water applications (AW) across m crops. Production is conditioned on the physical characteristics of the farm, α, where α is a vector of field characteristics such as soil type and slope. Production for each of the m crops is a quasi-concave function of acreage allocation and effective water application which is simply the product of water applied (AW) and the application efficiency (δ_j) of the irrigation system in place. Total crop production under the *j*th irrigation technology by the irrigator is then the function $f(\delta_j AW, l; \alpha)$. If the vector of crop prices is p, then revenues from crop production are given by $p'f(\delta_j AW, l; \alpha)$.

Production costs under the *j*th irrigation system are given by the function $C_j(AW, l)$ where all variables are as previously defined. Note that while production is determined by effective water, costs are a function of applied water. This is because water that is applied but not used by the crop must still be delivered to maintain a given level of crop consumptive demand. Consequently, one of the primary advantages of a more technically efficient irrigation system is the cost reduction associated with reducing the volume of water that is delivered but is not translated into productive yield.

In addition to the costs of actually producing under a given irrigation system, the limits of available water supplies must also be recognized. For the Colorado setting, the irrigator owns some share of a regional water supply. This ownership entitles the irrigator to an annual allotment of water, ω. At the regional level, water supplies are random and the actual realized value of ω is uncertain over time, but when supplies are not scarce the maximum amount of water the irrigator can receive is given by the upper bound of the irrigator's shares, or $\bar{\omega}$. If the expected consumptive requirements for a farm in a given year are Ω *AW, l*, then for an irrigator to actually produce in a given year the annual allotment of water must meet or exceed the expected consumptive water requirements for the farm given the farm's existing irrigation system. For the *j*th irrigation system, this implies $\delta_j \omega \geq \Omega(AW, l)$. For simplicity, ω can be represented by a binary distribution where $\bar{\omega}$ is received in full or it is not. The likelihood of $\bar{\omega}$ being received is θ and the likelihood of it being inadequate is simply (1- θ). This implies the irrigator faces the annual water supply constraint of $\delta_j \theta \bar{\omega} \geq \Omega(AW, l)$ under the *j*th irrigation technology.

Combining revenues and costs for the irrigator with this supply constraint gives the restricted profit function under the *j*th irrigation system for the whole farm, or:

$$\pi(p, \delta_j, AW, l; \alpha, \theta\bar{\omega}) = \max_{l,AW}\left[p' f_j(\delta_j AW, l; \alpha) - C_j(AW, l) : \delta_j \theta \bar{\omega} \geq \Omega(AW, l)\right] \quad (2)$$

Returning to the idea introduced by Caswell & Zilberman (1986) that an irrigator will choose the *j*th irrigation system over the *k*th system if it is more profitable implies that the decision to adopt a more technically efficient irrigation system under our present formulation is:

$$\pi(p, \delta_j, AW, l; \alpha, \theta\bar{\omega}) \geq \pi(p, \delta_k, AW, l; \alpha, \theta\bar{\omega}) \quad (3)$$

The adoption decision implied by equation (3) departs from existing irrigation technology adoption models in one critical aspect: it uses the irrigator's own water entitlements and the likelihood of receiving that water in place of water price. This specification is more in keeping with the institutional environment in Colorado and reflects the potential for a drought to induce a change in irrigation technology by disrupting the delivery of water.

The adoption decision suggested in equation (3) can be transformed into an empirically estimable discrete choice model by assuming irrigators maximize their profits in a random utility framework (Ben-Akiva & Lerman, 1985). Unfortunately, while equation (3) provides a general rule for adoption of more technically efficient irrigation systems that is compatible with the institutions of Colorado, as described it allows only for a discrete choice between two systems. That is, it involves only the choice of *j* over *k*. Given that farms in Colorado typically have multiple irrigation systems on different portions of the farm, what is needed is a model allowing irrigators to simultaneously choose both *j* and *k*. Fortunately, the discrete choice model can also handle this. Instead of an absolute choice between competing alternatives, the basic discrete choice model can also show the proportion of each choice selected by the decision maker. Within the context of irrigation systems this has been done to show regional irrigation technology choices (Schaible *et al.*, 1991; Schaible & Aillery, 2003), but in this instance it is at the farm rather than regional level.

Empirical Analysis

The model suggested by equation (3) can then be empirically estimated as a proportional limited dependent variable model with the percentage of each alternative irrigation system on the farm serving as the dependent variable and water supply as an explanatory variable.

However, there is a potential endogeneity issue inherent in the modelling of irrigation technology as a response to drought. Basically, to determine if drought causes irrigators to adopt some irrigation systems in preference to others, choosing irrigation systems changes as a drought response has to be an explanatory variable in the irrigation technology choice model. However, this choice is only made if there is a drought, so it is not an exogenous decision. The two questions are simultaneous, and must be modelled as such. This means two separate questions need to be evaluated: the observed choices of irrigation systems as a function of water supply and drought; and the decision to adopt an alternative irrigation system in response to drought.

Ideally, this would be estimated as a simultaneous system of multinomial limited dependent variable models, the first showing the proportion of each irrigation system present on a farm while the second shows whether or not the observed irrigation systems were chosen in response to drought. However, such systems are quite difficult to estimate and cannot be developed using conventional econometric programs. As an alternative, it is possible to estimate two individual equations. This would normally lead to a loss of statistical efficiency, but since the relationship between the two equations is unidirectional (the equation for the proportions of each irrigation system observed depends upon the decision to change systems due to drought, but the decision to change systems due to drought does not depend upon the irrigation systems at the time of observation), one equation depends upon the other equation but the reverse is not true. The covariance relationship between the two equations is therefore upper triangular in nature and can be estimated efficiently with two independent equations (Greene, 1993). This solves the endogeneity problem related to the decision to adopt a new irrigation system during the drought, yet still makes it possible to identify how the drought affected adoption rates across alternative irrigation systems.

Given this nature of the endogeneity problem, two separate equations are estimated here. The first examines whether or not irrigators chose to adopt new irrigation systems as a drought response, while the second examines their choices of irrigation systems as a function of drought. The first equation is a simple binary choice model, while the second is a proportional model describing what percentage of total irrigated acreage on a farm is covered by each of n different irrigation systems. The n different irrigation systems modelled here are: flood gravity, gated pipe and sprinklers. These are the three dominant types of irrigation systems found in Colorado, and account for over 99% of the irrigated acreage reported in the survey. Both equations follow existing literature and assume a logistic distribution for the choices modelled, so the first equation is estimated as a binomial logit while the second equation is estimated as a multinomial logit.

Data for the two equations come from a survey of 3496 agricultural producers throughout Colorado conducted by the Colorado State University Department of Agricultural and Resource Economics in conjunction with the Climate Diagnostic Center of the National Oceanic and Atmospheric Administration. For the survey, producers with operations covering more than 50 acres (1 acre = 0.4047 hectare) were drawn from the Colorado Agricultural Statistics Service producer database and mailed a questionnaire on 25 October 2002. A single reminder letter was mailed to survey recipients 1 week later following Salant & Dillman (1994). The overall response rate to the survey was approximately 30%.

The survey contained eight sections that asked questions about the farm's basic operations, water supplies, irrigated enterprises, dryland crops, livestock, drought responses, drought pressures and socio-economic characteristics. Most critically for this analysis, the section on drought responses included a specific question on whether or not irrigators adopted more technically efficient irrigation systems in response to the drought. A specific question identifying if the observed mix of irrigation systems on the farm was a direct result of the drought makes it possible to differentiate between the effects of chronically low water supplies (obtained from the portion of the survey dealing with available water supplies) and the specific shock of the 2002 drought. Having irrigators identify if their choice of irrigation systems was a specific response to the 2002 drought raises the previously mentioned endogeneity issue.

The 1100 usable responses for the survey represented a diverse cross-section of Colorado agriculture including livestock and dryland producers in addition to irrigators. Among irrigated operations, there was also significant variation regarding water source. To evaluate the question of drought impact on irrigation technology adoption, the sample was restricted to only irrigators who received water solely from mutual ditch companies. Mutual ditch companies are the most common type of irrigation water supplier in the state and provide good feedback regarding water deliveries over time. Inability to account for blending of other water sources, particularly groundwater, precludes the inclusion of respondents with additional water sources for the empirical estimation. This restriction resulted in 231 usable observations for this analysis, 20% of all questionnaires returned in the survey and nearly half of all irrigators.

The data used in the two logit models are described in Table 1. The first section contains variables that characterize the farm resource base. The relative measure of water deliveries as a fraction of full water supply filled for the irrigator during the 2002 drought is a strong indicator of the severity of the drought. On average, respondents received less than 35% of a full water supply in 2002 with some receiving full supply and some receiving none. The land resource was characterized by producers who averaged just over 150 acres of irrigated land with an average of just under 35 acres of corn and about 65 acres of alfalfa.

Table 1. Summary of response for 2002 drought survey

	Units	Average	Minimum	Maximum
Proportion of full water supply in 2002	%	34.7	0	100
Land				
Total irrigated land	Acres	156.6	0	11 620
Irrigated corn	Acres	33.6	0	1 460
Irrigated hay	Acres	63.5	0	1 400
Land leased	%	36.7	0	100
Land under irrigation system type				
Flood or siphon tube	%	51.2	0	100
Gated pipe	%	17.1	0	100
Sprinkler	%	31.7	0	100
Modified irrigation system in response to drought		11.3		
Proportion of income from agriculture	%	47.9	0	100
Education				
High school		32.8		
Some college		23.3		
Vocational/technical degree		8.1		
Bachelor's degree		23.9		
Graduate/professional degree		11.9		
Number of observations		231		

Irrigation system type was expected to influence the rate of technology adoption. On average, respondents were irrigating just over half of their irrigated acreage using flood or siphon tube technology. About one-sixth of the acreage was serviced by gated pipe and just under one-third by sprinkler. Individual producers varied from all to none of any given technology. When asked if adjustment in their technology choice for 2002 in was in direct response to the drought, over 11% of respondents indicated that their choice was dictated by the drought.

Two important demographic variables are also considered. First, the proportion of income derived from agriculture is expected to be important. On average, respondents indicated that just under half of their income was derived from agriculture. Finally, education often plays an important role in technology adoption decisions. The level of education was represented as an integer value with: high school = 1; some college = 2; vocational/technical degree = 3; bachelor's degree = 4; and graduate/professional degree = 5.

Results

Estimation of the proportional multinomial logit model was carried out using LIMDEP (Greene, 2002). The coefficients and *t*-values for the regression estimating the proportion of farmland serviced by gated pipe and sprinkler systems, respectively, are reported in Table 2. Based on standard measures of goodness of fit for logistic regression, the regression both fits the data well and is statistically significant.

Table 2. Multinomial logit results for proportion of land by irrigation system

		Gated pipe		Sprinklers	
Variable	Units	Coefficient	*t*-ratio	Coefficient	*t*-ratio
Constant		−0.68743	−1.408*	−1.63509	−3.165****
Share percentage	%	0.00914	1.574*	−0.00190	−0.314
Total irrigated cropland	Acres	0.00045	0.550	0.00108	1.798**
Irrigated corn	Acres	0.00246	1.131	0.00315	1.658**
Irrigated land leased	%	0.00166	0.370	−0.01267	−2.555***
Changed system in 2002	0/1	0.76761	1.365*	0.59438	1.034
Level of eduction	1/2/3/4/5	−0.15635	−1.250	0.21901	1.859**
Income from agriculture	%	−0.01389	−2.427***	0.00413	0.799
Model statistics					
Unrestricted log likelihood function		−208.622			
Restricted log likelihood function		−228.382			
Likelihood ratio statistic		39.521**** 14 degrees of freedom			
Number of observations		231			

Note: Significant at α = *0.15, **0.10, ***0.05, ****0.01.

Evaluation of individual coefficients shows that the proportion of land serviced by gated pipe is most significantly influenced by the proportion of income derived from agriculture. This is an inverse relationship where those producers with higher proportions of income from agriculture used significantly lower proportions of gated pipe. Competition for time would appear to be the driving factor in this result.

The decision to change irrigation technology in response to drought and the proportion of full water delivery received in 2002 also had a statistically significant impact on the proportion of gated pipe used. If an individual changed irrigation technology in the face of drought, they were more likely to increase the proportion of land serviced by gated pipe than those for whom drought did not prompt a change. The choice of gate pipe was further influenced by the degree of shortfall. A lesser shortfall in 2002 indicated a greater proportion of gated pipe whereas greater shortfalls indicated a shift away from gated pipe.

The prevalence of sprinkler technology was most significantly affected by land tenure, cropland acreage and level of education. The model reveals that greater proportions of land rented led to a lower proportion of sprinkler irrigation. This relationship should not be surprising as landowners' incentive to invest in capital equipment is diminished if the benefits are to be shared with a tenant. Under these circumstances, with the decision to invest in long-term irrigation technology in the hands of a landlord, one would expect a lesser rate of sprinkler adoption in land leasing situations.

Scale and intensity of land utilization had the opposite effect on sprinkler adoption. As total irrigated acreage increased, the proportion of land under sprinkler systems also increased. When scale of operation exerts pressure on labour resources, adoption of sprinkler systems is one means to alleviate the pressure. Similarly, more intensive and time-sensitive crops stand to garner more benefit from sprinkler technology. Greater acreage of corn, requiring more intensive management and being the major alternative to hay crops in the sample, translated into greater adoption of sprinkler systems.

Finally, level of education had a significantly positive effect on the adoption of sprinkler irrigation systems. The greater level of education attained the greater the proportion of irrigated land serviced by sprinkler irrigation. A number of aspects of education would be consistent with this finding such as greater technical skill required to operate most sprinkler systems or differences in lifestyle preferences.

The model can be used to estimate producer response under controlled conditions. One of the more interesting relationships revealed by the model is the proportion of land dedicated to production under different intensities of water supply. Figures 1, 2 and 3 demonstrate the expected response to water supply for gated pipe, sprinkler and flood technologies, respectively. Further, each figure differentiates the response for those who indicated that the drought prompted technology changes from those who did not.

The proportion of land dedicated to gated pipe increases as the water supply increases, as shown in Figure 1. Among those who were not prompted to change irrigation technology in the face of drought, a full water supply is predicted to correspond to an average of nearly 30% of acreage dedicated to gated pipe. For those making changes in response to the drought, the average proportion would be just over 40%. If water deliveries were only 50% of full supply, acreage proportion under gated

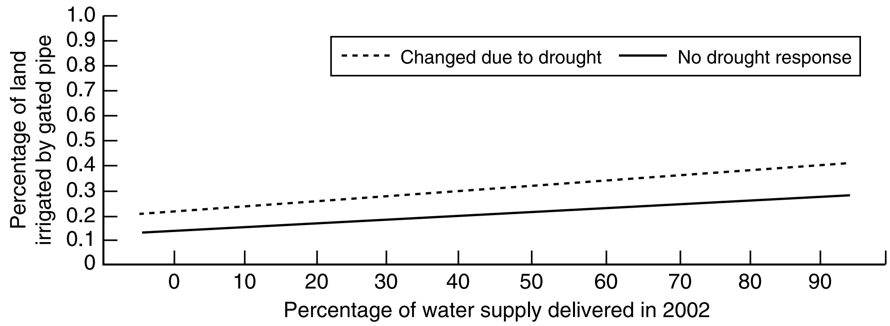

Figure 1. Proportion of land irrigated by gated pipe in response to water supply

pipe dropped to 30% and 20%, respectively, for those responding to drought and those who did not.

As shown in Figure 2, the proportion of land under sprinkler technology followed a similar, but more intense pattern. At full water supply, land under sprinkler technology was expected to account for about 50% of all irrigated land for those not prompted to change technology and over 60% for those changing. With only half of full supplies, the proportions dropped to 46% and 36%, respectively.

Finally, the residual impact on flood irrigation technology is shown in Figure 3. Here, the impacts are the opposite of the previous two cases. As water deliveries became more available, a lesser proportion of land was serviced by flood irrigation. Further, those responding to drought through technology adoption had an overall lower rate of flood irrigation use. At full water supply, those not responding to drought would average about 20% flood, whereas those reacting by upgrading technology would have none. At 50% water supply, the proportion of land under flood increases to 44% and 24%, respectively.

What these results seem to suggest is that the drought triggered some changes in irrigation systems, but most of the movement was from gravity/siphon to gated pipe. It is worth noting that this is the least capital-intensive transition and does have a noticeable effect on irrigation efficiency. Basically, producers were making the smallest investment

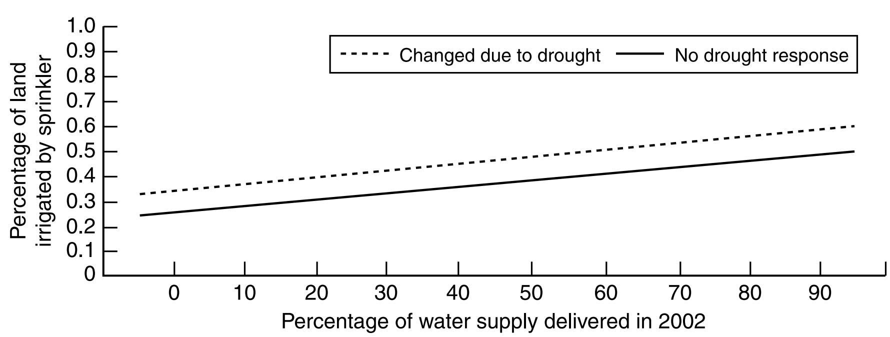

Figure 2. Proportion of land irrigated by sprinklers in response to water supply. *Note:* Evaluated at mean for total irrigated acreage, corn acreage, proportion farmland leased, education and percentage income from agriculture.

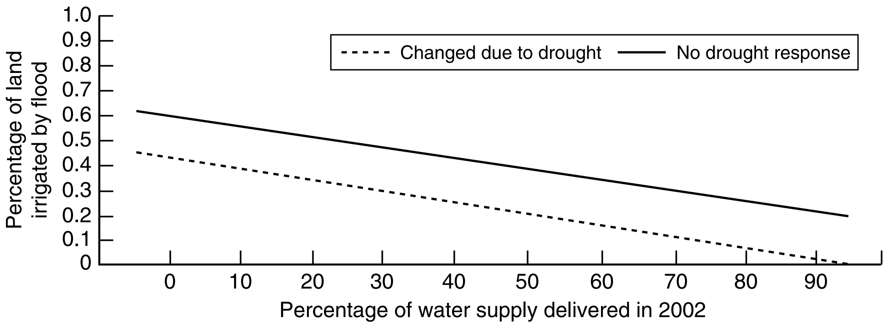

Figure 3. Proportion of land irrigated by flood in response to water supply. *Note:* Evaluated at mean for total irrigated acreage, corn acreage, proportion farmland leased, education and percentage income from agriculture.

possible to stretch their available water. In the long run, the trend might be different. In the case of this study, producers appear to have treated this as a single year disaster and not as a permanent shift in water supplies.

Conclusions

Improvements in the physical efficiency of irrigation systems are often suggested as a means of coping with short water supplies. Indeed, improvements in the technical efficiency of irrigation systems are a primary means of reducing on-farm water applications. However, little existing literature on the adoption of alternative irrigation systems focuses on response during drought periods. It is not clear how producers would respond in the face of severe drought conditions.

Econometric results reveal that source of income, scale of operation and land tenure are most significant in explaining the choice to move to more capital-intensive and, hence, more technically efficient irrigation systems. This is consistent with trends observed with the commensurate intensification that accompanies specialization in modern commercial agriculture in general. While drought itself appears to have triggered some changes in irrigation, it did not bring about wholesale changes in technology. In fact, among those who did adopt more efficient technology in response to drought, the changes tended to be relatively low-cost (e.g. moving from flood to gated pipe), suggesting a short-run response.

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