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Coping with Natural and Institutional Drought

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The Issue

Groundwater and surface water in the South Platte River basin of northeastern Colorado are hydraulically linked. Consequently, use of groundwater in the basin reduces surface water flows in the South Platte River. To avoid open-access problems in this situation, both surface water and groundwater in the basin are jointly administered under the prior appropriation doctrine. This gives preference to the earliest developed water rights relative to later rights when water supplies are insufficient to meet all demands. Groundwater development typically occurred after surface water development, so rights related to groundwater are generally sufficiently junior as to be exercised only in the wettest years. Historically, the state engineer has been empowered to allow groundwater pumping out of priority as long as the associated surface water depletion was replaced with a commensurate amount of water from an alternative source. During a severe drought in the summer of 2002, however, groundwater users pumped water in the expectation of alternative sources that never materialized. The Colorado Supreme Court later found that groundwater users were injuring senior water users by using water out of priority. Primary

policy questions arise as to the impact this out-of-priority pumping had on farm failures during the drought and the role water allocation institutions in the region played in allowing out-of-priority pumping.

Implications and Conclusions

Groundwater pumpers may have had access to water that should have gone to more senior water users – a potential redistribution of water supplies that is not consistent with the defined priority system. Such a redistribution may have enabled some farms to survive chronic droughts on other appropriators' water. As survey and econometric results show, groundwater users in the South Platte basin generally had higher water supplies during a severe drought than irrigators relying on surface water. This led to significantly lower rates of exit from agriculture for these farms than for farms relying on surface water alone. In direct response to this issue, the Colorado Supreme Court reaffirmed the necessity of including groundwater in the general system of appropriative water rights to avoid future uncertainty in the allocation of property rights for irrigation water.

Background

The summer of 2002 brought the state of Colorado drought conditions that reduced water flows in the South Platte River to less than 5 percent of normal flows. Fortunately, the return of average precipitation in the spring of 2003 provided at least a tenuous break from the grip of the drought. This respite allows an opportunity both to examine the impacts of the drought and to learn how people responded to drought. Such an examination will better prepare the people of Colorado and the western United States for the inevitable return to drought conditions, whether next year or a decade from now.

The drought affected Colorado's agricultural economy both directly and indirectly. Direct impacts were mostly damages in the form of production losses due to low water supplies. Indirect impacts came through the decisions forced on producers by a lack of water. The indirect effects arose from changes in production practices and enterprise management by individual producers; such decisions represent the aspect of drought that is under human control. Ideally, these decisions will mitigate the direct effects and improve the likelihood of a farm or ranch surviving a drought. Unfortunately, some do not.

The institutional environment influences decisions. By defining the legal framework in which irrigators operate, institutions establish the set of choices irrigators can make. This situation gives rise to the possibility of an "institutional" drought. An "institutional" drought occurs when institutional structures lead to water allocations or use decisions that accentuate physical scarcity. It is essential, therefore, to determine if existing institutional structures alleviate or exacerbate the effects of drought.

An example of institutional drought can be seen in the recent experience of groundwater users in the South Platte basin. The South Platte is one of the primary rivers

in eastern Colorado and provides drinking water to Denver and irrigation water to producers in both Colorado and Nebraska. Groundwater in the South Platte basin is considered to be "tributary" to the surface water system under Colorado's 1969 Adjudication and Administration Act (Hobbs, 1999). The statute recognizs that groundwater is hydraulically linked to flows in the river.

The Colorado Water Court administers and certifies appropriative water rights in the state (Hobbs, 2002). Groundwater usage, however, is administered by the state engineer of Colorado (Hobbs, 1999). Administration by the state engineer means that while groundwater use is legally included in Colorado's appropriative system of water rights, at a practical level the wells are approved outside of the Colorado Water Court. As such, wells can be approved without certified appropriative water-rights decrees. Because most groundwater wells were developed after surface waters, they are accompanied by junior rights that would not be fulfilled in dry conditions. However, statute allows out-of-priority utilization if the appropriator has a corresponding surface water right to compensate for reductions in surface flows caused by groundwater pumping (Hall, 2002).

These so-called augmentation plans are meant to fill the potential institutional gap in the joint management of ground and surface. Under this system, groundwater users are required to replace ("augment") surface water flows affected by out-of-priority groundwater pumping with either righted surface water flows or groundwater recharging with righted surface water. While some individual groundwater users employ their own augmentation programs, most augmentation plans are administered by public or quasi-public agencies. The two primary managers of augmentation plans are the Central Colorado Water Conservancy District (CCWCD) and the Groundwater Appropriators of the South Platte (GASP).

Each of these entities has followed a different path in its approach to augmentation. While the CCWCD holds and manages permanent water rights in its augmentation plan, GASP has relied on several different recharge schemes and on leasing water rights on an annual basis. During the 2002 drought, this difference in management became vitally important. The reason is simple: it takes time to identify a drought. While irrigators in both CCWCD and GASP started pumping groundwater prior to the growing season (early April), the full extent of the drought was not realized until June. At this time, several senior water-rights holders on the South Platte exercised their rights for water calls. These rights, dating to 1865 and 1881, were the most senior calls made on the river in over a generation (Hall, 2002).

Due to these calls, junior surface water appropriators found themselves without water that they believed was being taken by more-junior groundwater appropriators. Suit was filed to enjoin the groundwater appropriators from pumping out of priority and an injunction was granted. As a result, many acres serviced by groundwater wells lost their only source of irrigation water. The CCWCD, with its portfolio of water rights, was at least partially able to cover its out-of-priority pumping. GASP, which does not hold a

portfolio of water rights, found itself unable to obtain the replacement water needed. Clearly, they will not be allowed to continue to take water out of priority without major changes in their augmentation plan. The physical problem of a natural drought had been compounded by an institutional failure, in this case a gap in the priority system that allowed junior groundwater appropriators without corresponding surface water rights to use water in the expectation that no drought would occur.

From an economic perspective, this is a classic open-access problem. The split in administration of groundwater and surface water between the state engineer's office and the water court, coupled with lags in identifying droughts, enabled groundwater users to take water out of priority with no means of compensating senior water-rights holders. While the existing 1969 Adjudication Act appeared to fully include groundwater users in the state's system of appropriative water rights, the execution of this inclusion meant the open-access problem had not been solved. This set of circumstances makes the problem an "institutional" drought: physical scarcity that should not have affected senior water-rights holders became a problem when junior irrigators were granted access to groundwater.

Analyzing the Problem

The issue becomes a matter of assessment; specifically, what were the consequences to producers of the failure in the "augmentation" plans that allowed use of water out of priority? To assess both these effects and the effects of the drought in general, it is necessary to compare how irrigators' water supplies and decisions vary across different social institutions. In Colorado, the primary institutional difference across irrigators is how water is received; specifically, irrigators in the state typically receive their water from one of three sources: individual direct diversion; private or public mutual association; and direct pumping of groundwater. Irrigators' access to water will vary depending on the source of the water. Different levels of access, in turn, lead to irrigators making different types of decisions depending upon the source of their water. From a policy standpoint, the major issue is whether or not differences in water supplies and decisions across alternative water sources affect farm/ranch survival rates. By assessing how differences in water supplies and decisions across varying institutional contexts influence survival rates during periods of low supply, it is possible to determine if "institutional" droughts accentuate natural drought.

To analyze how Colorado producers changed their on-farm production practices in response to the drought, researchers in the Department of Agricultural and Resource Economics at Colorado State University, in cooperation with researchers from the Climate Diagnostic Center of the National Oceanographic and Atmospheric Administration in Boulder, conducted the "Weathering Tough Times" drought survey in the fall of 2002.

The survey questioned 3,501 randomly selected agricultural producers about changes in their farm and ranch management caused by drought. Producers with operations

covering more than 50 acres were drawn from the producer database of the Colorado Agricultural Statistics Service and mailed a questionnaire on October 25th, 2002. Following the Dillman procedure, a single reminder letter was mailed to survey recipients one week later (Salant and Dillman, 1994).

Questions in the survey covered all facets of agricultural production in Colorado, including irrigated and dryland farming as well as livestock grazing and feeding. Irrigators were asked to identify the sources of their water supplies, how much water (if any) had been received in 2002, and whether or not any of their water usage was part of an augmentation plan. Respondents were also asked both how they changed their production and water management practices in response to the drought and how these drought-induced decisions affected the farm's financial standing. The survey also explored the role of climate and weather information in decision making in response to the drought and asked how producers intended to respond in 2003 conditioned on whether drought conditions persisted or abated across the state. Finally, producers were asked what effect the drought had on the farm's financial health and the likelihood of their exit from agriculture. The latter question was vitally important. In it irrigators were asked to identify subjectively their probability of leaving agriculture both if the drought continued and if the drought broke. Consequently, this question can be used to quantify the incremental increase in the likelihood of a farm ceasing production due to drought-induced stress.

Building primarily on the survey data describing the likelihood of producers exiting agriculture, we conducted an assessment of institutional impacts on the weight of drought effects. For the empirical analysis, the sample was restricted to respondents from the South Platte and Arkansas River regions, since these are the two primary alluvial aquifers in the state (and therefore subject to augmentation plans), and respondents from the adjoining Eastern Plains region. While the latter region is generally not served by alluvial aquifers, it is similar in climate to the former two and provides a useful control to compare the general effects of drought in the state to the effects of drought in the regions served by alluvial aquifers.

The likelihood of exiting agriculture due to drought was estimated as a sample-selection ordered-probit model estimated in LIMDEP. A sample-selection ordered probit was used because approximately 60 percent of respondents indicated they would not exit agriculture under any circumstances, while the residual 40 percent indicated an average likelihood of exiting agriculture of 48 percent. As a result, it appears that enterprises are either at no risk of exit or rather pronounced risk of exit. The sample-selection model makes it possible to evaluate both the factors that differentiate enterprises at risk from enterprises not at risk, and the factors that influence the intensity of risk for enterprises in danger of exit. The two steps in the sample-selection ordered probit consist of a screening probit that evaluates the differences between at-risk and not-at-risk enterprises, while an ordered probit evaluates the level of risk experienced by at-risk enterprises. For the purpose of this study, the ordered probit divides at-risk enterprises into thirds: 0 for

Table 1 Summary of Survey Data for Eastern Colorado

	Eastern Plains	Arkansas River	South Platte
Irrigated acreage	451.186	366.642	187.869
Primary crop:		*Percent*	
irrigated corn	45.30	2.00	29.90
irrigated hay	23.40	80.40	48.20
Household members	2.79032	2.82963	2.89583
Age of respondent	55.3064	55.8222	55.6458
% of typical water supply filled in 2002		*Percent*	
all users	83.51	50.32	22.65
augmentation users	83.89	60.06	36.88
non-augmentation users	83.41	46.38	19.65
surface water users	57.00	44.81	20.11
Nature of water use:		*Percent*	
primarily groundwater user	50.32	22.65	55.31
participate in augmentation plan	14.10	17.60	26.30
Gross sales		*Percent*	
less than $50,000	31.15	51.06	42.06
$50,000 - $99,000	13.11	23.40	19.84
$100,000 - $249,000	24.59	19.15	17.46
$250,000 - $499,000	21.31	4.26	11.90
$500,000 - $1,000,000	8.20	2.13	3.17
over $1,000,000	1.64	0.00	5.56
Debt load		*Percent*	
no debt	16.67	17.78	32.03
less than 0.25	11.67	20.00	20.31
between 0.25 and 0.5	18.33	15.56	15.63
between 0.5 and 0.75	18.33	20.00	7.81
between 0.75 and 1	3.33	2.22	1.56
over 1	6.67	2.22	0.78
debt/equity ratio unknown	25.00	22.22	21.88

operations between 1 percent and 33 percent likelihood of exiting, 2 for operations between 34 percent and 66 percent likelihood of exiting, and 3 for operations with a probability of exiting over 67 percent. Nearly 60 percent of the at-risk operations are in the upper two categories of risk.

Table 1 describes the data used in the regression. To start, irrigators participating in an augmentation plan are identified through a dummy variable for augmentation plan participants (*participate in augmentation plan*). Irrigators can receive water from one of

three sources: groundwater from an on-farm well, surface water from a direct diversion, or surface water from either a public or private irrigation system. Irrigators using groundwater as their primary water source were identified with a dummy variable (*groundwater user*). The three main crops in the three regions used in the study are irrigated corn, irrigated hay, and irrigated grain. To capture variations across alternative crops, corn producers are identified by the *corn* dummy variable while hay producers are identified by the *hay* dummy variable. Total farm irrigated acreage is conveyed through the *irrigated acreage* variable, while *age* and *household* capture the age of the producer and the size of the household, respectively. Additionally, the fraction of typical water supply filled for the irrigator during the 2002 drought is also included (*% of typical water supply filled in 2002*) as are the water supplies available to groundwater users, augmentation plan participants, and surface water–only users. Note that the highest supplies are available to augmentation plan users; this is in direct opposition to expectations given Colorado water law.

The last two variables are categorical in nature. As part of the survey, irrigators were asked to identify their gross farm sales on a similar scale. The range for gross farm sales was: less than $50,000 = 1; $50,000 to $99,000 = 2; $100,000 to $249,000 = 3; $250,000 to $499,000 = 4; $500,000 to $1,000,000 = 5; and over $1,000,000 = 6. Irrigators were also asked to identify their current debt-to-equity ratio on a scale from 0 to 6. These were: no debt = 0; less than 0.25 = 1; between 0.25 and 0.5 = 2; between 0.5 and 0.75 = 3; between 0.75 and 1 = 4; over 1 = 5; and debt/equity ratio unknown = 6. Debt/equity ratios are also expressed as an interaction term relative to irrigated acreage, primarily to account for wealth effects associated with larger land holdings.

Collectively, these variables were used to determine first if a producer was at risk of exiting agriculture, and, if the producer was at risk, how much at risk. As mentioned previously, the estimation was carried out in LIMDEP as a sample-selection ordered probit. Typically, this kind of estimation is carried out in two parts, with the first stage consisting of an independently estimated *probit* screening equation being used to estimate starting values for an independently estimated *ordered probit* assessing the intensity of risk for at-risk producers. In the second stage, initial estimates from these two independent equations are integrated into a single, full-information, maximum-likelihood model (FIML).

A FIML approach has marked efficiency advantages over a two-stage estimation approach; however, in this case only the first-stage, independently estimated equations were necessary. The rationale for the FIML is that the error terms between the screening equation and the intensity equation are correlated in a bivariate normal distribution, but here the correlation between the error terms in the two first-stage estimators was only 4 percent and the autoregressive term accounting for correlation between the two equations in the FIML was not significantly different from zero. For these reasons, there

Table 2 *Probit* Regression Results for Being at Risk of Exiting Agriculture
Due to Drought

	Units	Coeff.	t-value
Constant		1.67188	2.15934**
Arkansas	0/1	0.446493	1.23536
E. Plains	0/1	0.327327	0.821667
Irrigated acres	acres	0.001064	1.87536*
Arkansas* irrigated acres		-0.00137	-1.31493
E. Plains* irrigated acres		-0.00082	-1.20015
Corn	0/1	0.017452	0.061792
Hay	0/1	0.272636	0.935644
Gross sales	1/2/3/4/5/6	-0.20175	-2.21221**
Debt/equity ratio	0/1/2/3/4/5/6	0.140159	2.50049**
(Debt/equity ratio) /irrigated acres		-8.51251	-2.11668**
Augmentation	0/1	0.650484	2.60683***
Age	years	-0.03578	-3.67734***
Household	people	-0.15762	-1.75388*
Groundwater user	0/1	0.402663	1.53271

Goodness of fit:	% correct	68.60
	Likelihood ratio test	44.99***
	d. of f.	14
	McFadden's R^2	0.160114
Significant at =	10% *	
	5% **	
	1% ***	

is no efficiency loss in independent estimation of the two stages, and estimation of the FIML is not warranted.

Table 2 reports the coefficients and t-values for the first-stage regression distinguishing between at-risk and not-at-risk enterprises. Based on two standard measures of goodness of fit for logistic regression, the McFadden's R^2 and the likelihood ratio test, the regression both fits the data well and is statistically significant. The model also successfully predicts at slightly over 68 percent. Evaluation of individual coefficients shows that regional variations and cropping patterns, as indicated by the respective dummy variables, are not significant. The coefficient for irrigated acreage, however, is positive and marginally significant. This suggests that larger operations are somewhat more likely to be at risk than smaller farms. Conversely, the coefficient for gross sales is strongly significant and negative, indicating that farms with higher levels of gross sales are less likely to be at risk. Additionally, the coefficients for higher levels of debt (or unknown debt) are significant and associated with a higher likelihood of being at risk of

Table 3 *Ordered-Probit* Regression Results for Likelihood of Exiting Agriculture Due to Drought

	Units	Coeff.	t-value
Constant		0.064617	0.066751
Irrigated acres	acres	7.34E-05	0.076469
Arkansas* irrigated acres		-0.00185	-0.87825
E. Plains* irrigated acres		0.001391	1.74782*
Corn	0/1	-0.25144	-0.39012
Hay	0/1	1.493	1.92745*
Gross sales	1/2/3/4/5/6	0.5232	2.04767**
Debt/equity ratio	0/1/2/3/4/5/6	0.271143	1.79149*
(Debt/equity ratio) /irrigated acres		-6.34635	-0.59411
Augmentation	0/1	0.522559	1.0789
Groundwater user	0/1	0.461592	0.704662
% of supply in 2002	%	-0.02859	-2.11304**
Education	1/2/3/4/5	-0.46276	-2.82051***
Household	people	-0.21455	-1.13194
Federal assistance	0/1	1.27403	1.95878*
Exit w/o drought	%	0.026294	3.63418***
	Mu(1)	1.92138	3.97834***

Goodness of fit:	% correct	71.43%
	Likelihood ratio test	59.33344***
	d. of f.	15
	McFadden's R^2	0.398617
Significant at =	10% *	
	5% **	
	1% ***	

exit, although higher levels of debt are less critical in the case of operations with higher acreage levels, perhaps due to wealth effects of larger land holdings.

From a policy perspective, the coefficients of primary interest relate to groundwater use and augmentation plan participation. While groundwater use is not in and of itself a significant determinant of risk for producers, participation in an augmentation plan is. More importantly, participation in an augmentation plan is associated with a positive and significant increase in the likelihood of being at risk. This is in keeping with the junior status of producers who rely on irrigation water in augmentation plans.

The question then becomes how much of an increase in the likelihood of exit stems from this increase in the likelihood of being at risk associated with being in an augmentation plan. Evaluation of this point requires turning to the second regression. In the second regression, the severity of risk for at-risk producers was evaluated through an ordered probit (table 3). For the most part this regression replicated the regression from

the first stage, but with a few key distinctions. In this regression, the region-specific dummy variables were dropped due to insignificance (but the region/irrigated acreage terms were preserved). The demographic variable a*ge* was also dropped and replaced by the categorical variable *education,* which ranges from 1 to 5 and extends from high school (1) to post-graduate education (5), with some college (2) representing the mode. Additionally, the water supply variable (*% of water supply in 2002*) was included, as was a dummy variable for participation in federal assistance programs (*federal assistance*).[1] To account for the fact that some producers were under greater risk of exit before the drought, the likelihood of exiting without a drought (*exit w/o drought*) was also included; this averaged about 38 percent across all at-risk producers, approximately 10 percent less than their risk of exit during the drought.

For the most part, the second regression also performed reasonably well. The regression as a whole is significant according to the likelihood ratio test and predicts successfully at slightly over 71 percent, with several individually significant variables. Individually significant variables include gross sales, debt, water supply, non-drought risk and participation in federal assistance. Insignificant variables include both the groundwater and augmentation dummy variables as well as the acreage and debt/acreage measures. The fact that neither the groundwater nor the augmentation dummy variable is significant in the ordered probit suggests that while these types of irrigators are more likely to be at risk due to their junior appropriator status, the degree of pressure they experience is more a function of management indicators such as gross sales and debt.

Unfortunately, the coefficients in an ordered probit are notoriously difficult to interpret, and the sign may not even indicate the direction of the marginal effects for a specific variable (Greene, 1993). To show how the likelihood of being in a given category of risk changes across different sources of irrigation water, the probability of being in a given category of exit risk was calculated across different types of water users. These results appear in table 4. As the figures in table 4 indicate, the probability of being in the highest category of exit risk is lowest for participants in augmentation plans. While participation in an augmentation plan is not in and of itself significant, the higher water supplies reported by augmentation plan participants markedly reduced their likelihood of being in the highest category of exit risk. Consequently, it appears that while augmentation users are more likely to be at risk of exit than other types of water users, the fact that augmentation users received higher supplies of water in 2002 reduced their overall level of risk.

Since, typically, junior irrigators use groundwater or participate in augmentation plans in the South Platte basin, they are less likely to leave agriculture than irrigators who rely on more senior surface water rights. This is exactly counter to the way appropriative water rights are designed to operate in Colorado. Based on these initial results, it does appear that water delivery institutions in Colorado are not sending water to their intended users.

Table 4 Probability of Being in a Given Risk Category for Different Types of Water Users in the South Platte Region

Probability Category	Augmentation user	Non-augmentation user	Surface water user
	Percent		
Prob (Y = 0)	7.48	2.70	2.70
Prob (Y = 1)	60.97	47.08	47.08
Prob (Y = 2)	31.55	50.23	50.23

Note: Assumes average acreage irrigated hay producer in the South Platte with gross sales of less than $50,000/year, a debt/equity ratio over 0 and less than 0.25, with 2 people in the household and some college education. Y = 0 is for producer with risk between 1 percent and 33 percent; Y = 1 is for producer with risk between 34 percent and 66 percent; and Y = 2 is for producer with risk over 67 percent.

This is an example of an institutional drought, where an institutional failure compounds the physical scarcity of water in a system.

While the results indicate that the probability of leaving agriculture is inversely related to water supply, the results also suggest that the farmers most at risk to leave agriculture are the types of water users that are generally the most senior (surface water users with a direct diversion right). At the same time, survey results indicate that the junior users are least likely to exit because it appears that they inadvertently received more supplies than their more senior counterparts. The ability of junior water users in augmentation plans to use water without having corresponding rights at the time of use appears to have enabled this misallocation of water during the most severe drought in Colorado's history. On the whole, it appears that current institutions may not have sent the intended signals about which operations should be exiting during a time of drought.

Summary and Conclusion

The drought in Colorado during the summer of 2002 was arguably one of the worst in the state's recorded history. This drought made evident certain gaps in the state's system of water distribution that allowed some irrigators to pump water out of priority. As the empirical results show, water users in the class of irrigators who were allowed to pump out of priority are significantly less likely to leave agriculture than irrigators in water-use categories that should have priority.

This is an example of an institutional drought – in this case the inadvertent redistribution of water from senior users to junior users due to unforeseen inconsistencies in Colorado's water laws. However, this decrease in the likelihood of exit for groundwater users is not the post-script to this situation. The final outcome was a revision of both appropriative rules in the South Platte region and a modification of state water law to

ensure that this type of situation cannot happen again. The conclusion, then, is not only that an institutional weakness made a drought worse – but also that it prompted institutional changes aimed at preventing a recurrence of these events.

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Endnote

[1] Only about 9 percent of all survey respondents sought general federal drought assistance. Given this relatively low percentage of participation, the variable was collinear in the screening *probit* model but was successfully included in the *ordered-probit* model.