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Groundwater Conservation Policy in Agriculture

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Introduction

Agriculture uses a clear majority of the surface and groundwater resources utilized by the human community in most regions of the world. Allocation conflicts between the agricultural sector and the sectors representing municipalities, industry and even the environment are increasingly prevalent in arid and semi-arid regions. Policy debates over water quality, water quantity, water conservation, endangered species, and property rights increasingly dominate the domestic and international political agenda (Anderson; Donahue and Johnston; Gleick; Postel).

Emerging public tensions were evident in central Arizona throughout the 1960's and 1970's over the role of groundwater in meeting the future water demands of a growing urban population and a prosperous agricultural sector. A series of three major events led the state's political leaders to the negotiating table to fashion legislation promoting the conservation and management of groundwater (Burton; Connall). First, a series of legal decisions (Jarvis I, II, and III) eventually established the right and quantified the amount of water cities could extract from off-site municipally-owned wells, generally in rural areas, and transport the water to municipal consumers. Secondly, the court determined in the Farmers Investment Company case that mines could no longer withdrawal groundwater from neighboring lands and transport the water away from those lands for use in the mining operations because of the damage done to neighboring wells. This court ruling threatened the ability of mines and cities to meet their long-term water needs without buying large acreages of farmland. Finally, within this uncertain legal environment, the federal government threatened to discontinue funding for the Central Arizona Project (CAP), a 336-mile aqueduct importing Colorado

River water into central Arizona, unless the state passed a comprehensive groundwater management code.

The Groundwater Study Commission, created by the state legislature in 1977, was charged with studying the possibility of a comprehensive groundwater law reform. Specifically, the Commission was given the responsibility to (1) clarify conflicting groundwater rights claims, including transportation rights, (2) design a management plan for critical overdraft areas, (3) institute a program to encourage efficient water use, (4) manage water for future population growth, and (5) protect the environment. After two years of intense negotiation between mines, cities, and agriculture, the Groundwater Management Act (GMA) was signed into law on June 11, 1980. The Arizona Department of Water Resources (ADWR) was established in the GMA to implement and enforce the new water code. The GMA has won acclaim and awards over the years for its approach to groundwater management (Woodard).

The GMA initially established three Active Management Areas (AMAs) in three important agricultural/urban areas where a long history of groundwater overdraft (nearly 2 million acre-feet per year) threatened the long-term viability of farming and urban expansion. The legislative goal in the Phoenix and Tucson AMAs was safe yield or zero overdraft in 2025. In the Pinal AMA, a relatively more agriculturally dependent region, the goal was to preserve farming as long as possible without jeopardizing municipal water supplies. Water conservation practices, in all economic sectors, was encouraged via increasingly restrictive policies on water use.

In the case of agriculture, the GMA regulated water conservation by (1) not allowing the development of new agricultural land, (2) requiring the ADWR Director's approval to drill new, non-replacement wells in the AMA, and (3) a series of management plans that gradually reduced the quantity of water available to the grower in a given year. The annual water allotments (A) represented the amount of water a farmer could use from wells and/or surface supplies where:

(1) $$A = W * L$$

(2) $$W = (I/E),$$

and

(3) $$E = CWR/w.$$

From (1)-(3) above, W is the irrigation water duty, and L is the highest number of acres farmed during the period of January 1, 1975 to January 1, 1980. I is the annual irrigation requirement per acre for the crops grown on the farm during this same period. E is the assigned irrigation efficiency (e.g. 75%), where CWR is the crop water requirement and w is the actual volume of water applied. ADWR had policy discretion over two variables used to establish the annual water allotment, E and I. An irrigation efficiency of 65% was established in this first period, with the expectation that E would be set at 75% and 85% in the second (1990-2000) and third (2000-2010) management plans, respectively. By increasing E, ADWR expected to induce growers to adopt water-conserving irrigation practices as their water allotment declined. I was set by ADWR at 5.05 acre-feet per acre per year in the first management period, 1980-1990.

Actual water use was measured with flow meters on all wells and irrigation district-managed turnouts in all AMAs. If a farmer used less water than A in equation 1, the grower could bank the difference in a flexibility account (i.e. flex credits). In water short years due to increased cropped acreage and/or high ambient temperatures, the grower could borrow from the flex account in order to maintain the economic productivity of the farm.

No formal assessment of ADWR's agricultural water conservation program has been conducted during its nearly 25-year implementation period. Most reflections on the agricultural provisions of the GMA are descriptive and fail to quantify the program's degree of success in promoting water conservation in agriculture (Jacobs and Holway). One economic evaluation effort, using a mathematical programming model to simulate expected water use in the agricultural sector, concluded that neither improved water conservation practices or technologies, or agricultural land retirement would assure safe yield in 2025 as required by the GMA (Cory et al.). More general reviews of groundwater conservation programs and technologies do not formally evaluate existing public programs (Parker and Tsur; Koundouri).

This paper outlines the conceptual framework used to evaluate the impact of GMA regulations on water use in central Arizona's agricultural sector. This impact assessment then tests the hypothesis that the GMA had minimal impact on agricultural water conservation over 20 years. Our qualitative and quantitative results indicate that water use in the agricultural sector has remained constant over the study period, and crop prices and rainfall explain most variability in water use, not the GMA's management plans. The paper concludes with a brief discussion of the implications for Arizona and other water management entities interested in agricultural water conservation programs.

Methods

Program evaluation systematically analyzes the efficiency and effectiveness of program processes and/or outcomes relative to program goals (Rossi, Lipsey and

Freeman). Evaluations are conducted for a myriad of reasons, among them (1) outcome assessment, (2) implementation improvement, (3) oversight, and (4) knowledge generation. Generally and ideally, evaluations generate future social improvement, either directly or indirectly. The "big tent" of evaluation tools contains many evaluation approaches, methods, and purposes (Mark, Henry and Julnes). Stufflebeam analyzed and ranked 22 widely-used evaluation models. He concluded that eight approaches (e.g. decision/accountability, client-centered/responsive, case study, and outcomes monitoring/value added) ranked "very good" and should receive preference in 21st century evaluations.

Published evaluations by economists of agricultural water conservation programs in the US are limited in number and scope. Most of the professional literature focuses exclusively on farm-level technology adoption utilizing standard benefit-cost analysis methods (Caswell and Zilberman; Coupal and Wilson; Anderson, Wilson and Thompson). Adoption decisions of water conserving technology depend, according to this literature, on appropriate soil conditions, increments in yield, water savings, and the availability of investment resources. Only in rare circumstances do evaluators forecast potential water savings in the sector associated with these technologies (Ayer, Wilson and Snider). Evaluations of ongoing, public-supported water conservation programs, on a program-wide basis, are strikingly absent in the public domain.

Denzin's triangulation approach to program evaluation characterizes our mixed-method impact analysis (Mohr). Triangulation inherently contains checks and balances for the analysis—giving the evaluation greater strength and rigor than single method evaluations (Patton). Our impact analysis design triangulates with analyst, data, and method (qualitative and quantitative). We interviewed ten irrigation district managers, eleven current or former staff members of ADWR, and nine water experts, analysts, and growers, thirty interviews in all. We also gathered water purchased, water pumped, price, weather, and acreage data for eleven irrigation districts in the three AMAs for the period 1984–2002. These eleven districts represent 69 percent of the irrigated acreage in these AMAs. This data, along with an ADWR water use data set, allowed us to conduct statistical analysis of water demand across time in eleven irrigation districts. With structural, institutional, and operational knowledge of these districts, we explain the majority of the variation in water demand across districts. Also, we test the impact of the Second and Third Management Plans of the GMA on agricultural water demand.

Qualitative Analysis

Responses to open-ended questions form the foundation of the qualitative analysis. Three identical questions were directed at individuals:

1. In your opinion, has the 1980 Groundwater Management Act been an effective policy for agricultural water conservation? Why or why not?

2. If it had been your responsibility, how would you have designed a GWMA in the year 1980 to promote agricultural water conservation?

3. In your judgment, how could the current water conservation program in agriculture be improved?

These responses yielded shared insights and explanations for the degree of impact of the GMA on agricultural water use.

Quantitative Analysis

We pooled water purchased and pumped, water price, commodity price, and weather variables for the eleven irrigation districts for the period 1984-2002. This panel data series has the benefit over cross-section or time-series data in that it controls for individual heterogeneity (Baltagi). Panel data suggest that individual irrigation districts are heterogeneous, avoiding the risk of obtaining biased results. Panel data produces more information, more variability, less collinearity, more efficiency, and more degrees of freedom than the other types of data series. Finally, panel data allows the researcher to study the dynamics of adjustment.

For this impact assessment, we estimate the following model:

$$\text{(4)} \qquad \ln w_{it} = \alpha_i + \beta_1 \ln (wp_{it}) + \beta_2 \ln precip_{it} + \beta_3 \ln temp_{it} + \beta_4 \ln alfp_t + \beta_5 \ln barp_t + \beta_6 \ln cotp_t + \beta_7 \ln whep_t + \beta_8\, GMA_2 + \beta_9\, GMA_3 + \varepsilon_{it}$$

where w is the water purchased and pumped (acre feet) in the i^{th} irrigation district (i = 1,…,11) in year t where t is 1,…,19 (1984-2002). The price paid for irrigation water by the grower is *wp*. The expected sign is negative because water purchased decreases as the price of water increases for the farms in the irrigation district. *Precip* represents the annual rainfall in i^{th} district in year t. Precipitation is expected to have a negative sign because rain and irrigation water are substitutes. We hypothesize that *temp*, the average temperature during the growing season March to September, will have a positive sign. Alfalfa (*alfp*) and cotton (*cotp*) prices are expected to have positive signs. A higher alfalfa or cotton price will yield more acres planted to alfalfa or cotton causing more water to be purchased. The sign for wheat (*whep*) and barley (*barp*) prices is expected to be negative because they are relatively lower water demand crops. GMA_2 and GMA_3 are dummy variables for the implementation periods of the second and third management plans. We hypothesize that the coefficients on the dummy variable for the second and third management period will be negative, implying a policy impact on reducing water consumption in the agricultural sector.

Results and Discussion

Water experts in the state share the belief that individual farms adopted water conservation technologies in the late 1970s and throughout the 1980s. The passage of the GMA created a perception of an impending, and binding water constraint. The fear that this legislation could hurt agricultural operations in the future induced some growers to line their ditches, laser level their fields, and improve water management practices. Simultaneously, the impending arrival of CAP water in central Arizona encouraged some farmers to level fields, create level basins in their fields, and construct high volume turnouts. Experts agree that individual farms adopted water conservation improvements during the study period but that most of these decisions had very little to do with the conservation requirements in the first, second and third management plans. The only legislated policy that “conserved” water for the future, according to the interviewees, was the requirement that irrigated acreage could not be expanded in the AMAs beyond the acreage in the 1975–1979 period.

So why did the GMA have little direct impact on water conservation decisions in agriculture? First, the Act and the implemented management plans did not establish an effective water constraint for most farms. Rather, the legislation established a “constraint” that was not binding on the decision making of most growers. The GMA established 1975–1979 as the period used to determine water duty acres and authorized the highest number of acres irrigated during this period to receive a water allocation. This period represents the peak of irrigated acreage in central Arizona over the last forty years. To compound matters, ADWR calculated a generous water duty based on average crop needs during 1975–1979 for the first management plan. As a result, most growers, but not all, felt no binding water constraint on their irrigation water use.

A second factor in creating an ineffective water constraint was the design and implementation of the flex account program beginning in 1986–1987. Growers now had the right to "bank" portions of their water allotments that were not used in a given year. Farmers could accumulate these credits over the years and withdraw them when they increased their cropped acreage (within GMA limits), experienced a hot summer, grew more water-intensive crops, or farmed more intensively. They also could sell a limited number of credits to other farmers within their district or groundwater sub-basin after the GMA amendments of the 1990s.

Accumulated flex credit accounts have grown to tens of thousands of acre feet of water for individual farms for several reasons. First, during the 1980s the agricultural economy went through a period of low commodity prices and high interest rates. Low profitability and credit constraints reduced acreage planted and water use, but increased flex credits. Secondly, until 1996, federal commodity programs required growers to set aside a portion of their land to receive commodity program payments. These set-aside acres earned flex credits. At present, the average flex credit account in the three AMAs represents six years of irrigation water for the "average" grower. In summary, generous water allotments combined with generous flex credit provisions created a decision environment in agriculture where water availability was not a binding constraint for most growers.

Our quantitative, econometric results are consistent with these qualitative findings. Using a log-log econometric model for water demand (equation 4), corrected for heteroskedasticity and autocorrelation, we find that water prices, crop prices, and weather explain nearly all the variation in water purchased and pumped over the study period (Table 1). The price elasticity of demand for agricultural irrigation water is -0.111 and is significant at the five percent level. Weather variables (precipitation and temperature) have the hypothesized signs and are statistically significant. All commodity prices have the hypothesized signs but are not statistically significant. Conservation provisions in the second and third management plans had no noticeable impact on the quantity of water utilized by growers, even obtaining a positive sign in the model rather than the negative hypothesized sign.

Growers respond to market signals when evaluating the profitable adoption of water-conserving irrigation technologies and practices. Declining crop prices and low, stable water prices over the last half of the study period served as disincentives to the adoption of costly technologies or to a significant change in water management practices. Aggregate water use in the agricultural sector has declined slightly due to urbanization in some of the irrigation districts in the Phoenix AMA. However, the trend in per acre water use in the agricultural sector has remained relatively constant over the life of the GMA. A final note: it is important to realize that groundwater has been conserved in the three AMAs over the later half of the study period because low-cost CAP water has been available to the agricultural sector. As a result of favorably priced CAP water, overall water use and irrigation rates per acre in agriculture have remained remarkably constant over the study period.

Conclusion

The GMA has raised the visibility of water issues in the state over the last twenty-five years. Required recordkeeping, reports, planning, and negotiation sensitized the agricultural sector to its important role in the management of water resources in the state. The GMA currently serves as a valuable framework for policy analysis and discussions. However, the agricultural water conservation provisions of the second and third management plans of the GMA by themselves did not create significant incentives for on-farm water conservation practices and technologies. While many growers have adopted water conservation practices and technologies over the past twenty-five years, factors other than the management plans have been largely responsible. The GMA changed the political environment, but the management plan provisions did little to change the economic incentives or water management decisions of most agricultural business managers. Many water experts interviewed for this study concluded that some combination of education (e.g. irrigation management assistance), a best management practice program, and economic incentives (e.g., tax credits, cost shares) could have been lower cost and more effective tools for achieving desired water conservation goals in Arizona's agricultural sector.

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Table 1: Fixed Effects Water Demand Model for Central Arizona Irrigation Districts

	Corrected Fixed Effects	
Variable	Coefficient	Std. Error
Intercept	---	---
Ln (Water Price)	-.111*	.056
Ln (Annual Precipitation)	-.134**	.004
Ln (Average Temperature)	.249*	.011
Ln (Alfalfa Price)	.069	.135
Ln (Barley Price)	-.076	.205
Ln (Cotton Price)	.138	.221
Ln (Wheat Price)	-.088	.121
Second Management Plan	.085	.081
Third Management Plan	.085	.123
Buckeye WC	9.704**	.548
Central Arizona IDD	10.607**	.644
Cortaro-Marana IDD	8.808**	.483
Hohokam IDD	9.598**	.561
Maricopa-Stanfield IDD	10.606**	.645
New Magma IDD	9.518**	.571
Queen Creek IDD	8.886**	.537
Roosevelt IDD	10.315**	.568
Roosevelt WC	9.758**	.595
Salt River Project	10.617**	.628
San Carlos IDD	10.210**	.612
Degrees of Freedom	192	
R^2	.9824	

*Significant at 5% level **Significant at 1% level