INDIVIDUAL AND INSTITUTIONAL RESPONSES TO THE DROUGHT: THE CASE OF CALIFORNIA AGRICULTURE

David Zilberman, University of California Berkley
Ariel Dinar, World Bank
Neal MacDougall, California State, San Louis Obispo
Madhu Khanna, University of Illinois
Cheril Brown, University of West Virginia
Frederico Castillo, University Of California Berkley

INTRODUCTION

Drought is one of the biggest and devastating events that mankind has witnessed throughout the world. The determination of the drought onset or end, as well as its severity, is difficult. It is a gradual phenomenon, its impact can, nevertheless, be devastating. The drought's impacts are dependent not only on the duration, intensity, and geographical extent, but also on the demands by human activities, flexibility of the region's water storage and supply, and the institutions of the delivery system. They evolve over time and are influenced by the interactions between supply and demand. Drought events and adaptation throughout the world have been documented in Yevjevich et al. (1983), Wilhite et al. (1987), and Wilhite (1993).

A comparative study of drought policies (Wilhite, 1986) suggests that governments often respond to drought through crisis management rather than preplanned programs. A National Research Council study argues that public agencies respond to water shortage, mainly by adjusting water supply. Easterling and Riebsame (1987) assess drought impacts and adjustments in agriculture and water resource systems. They emphasize dynamic adjustments to reduced water availability, but have very little behavior analysis explicitly understanding the role of incentives and economic consideration affecting water use.

Documentation on droughts in California includes data on water inventories and allocation, a summary of policies, rationing of water by urban communities, and changes in state water allocation to urban and agricultural users (DWR, 1977; DWR, 1991). These reports also provide the impacts on ground water quantity and quality and economic consequences on agriculture and the urban areas. This paper is concerned with the 1987-1991 drought in California and its impact on the agricultural sector. California is an example of a state that relies heavily on water harvesting projects because it is very sensitive to rainfall and drought conditions. California is basically a desert state that invented itself by water. A drought that long and significant has not been observed and documented before. More detailed presentations of the results of the paper appear in Zilberman et al., 1998).

This paper demonstrates that responses to the recent California drought are consistent with the prediction of economic theory. It also shows that a distinct event such as a drought leads to major changes in institutions and technology. The prevalence of traditional irrigation technologies, large proportions of acreage allocated to water-intensive crops, and rarity of water marketing in California might have contributed to skepticism about the capacity of financial incentives and scarcities to induce changes in water-use patterns and institutions in the state. Evidence of the behavior of various decisionmakers at farm, water district, and state project levels during the drought are presented here to document the responsiveness of California water users and institutions to water scarcities. The paper interprets data from several sources, including findings of two surveys, without formal modeling. The results speak for themselves, are accessible to noneconomists, and are unadulterated by the statistical assumptions necessary for econometric estimations.

The results of this paper confirm the importance of water reservoirs in stabilizing surface water supplies. Because of these reservoirs, farmers were not affected noticeably during the first three years of the 1987-1991 California droughts. Only during the last two years of the drought water supply to junior rights owners was reduced markedly, and the responses were increased pumping of ground water, adoption of water conservation technologies, and fallowing of land. The last year of the drought also witnessed an important institutional change, namely, introduction of water trading.

While the results of the paper confirm the importance of economic incentives and forces in response to changes, it also suggests a weakness in our economic education and analysis. Differential calculus is used to derive many results in economics. Textbooks such as Teitenberg mostly educate the students to think in terms of continuous response of the system to small changes. In many cases the system is rigid and small changes in prices and other parameters may not induce significantly observed changes in behavior. On the other hand, massive changes such as the ones changed by the drought resulted in substantial changes and behavior that are consistent with the prediction of economic theory. That suggests that economists should develop analytical tools and emphasize analysis that deals with extreme events.

BACKGROUND

California is the leading agricultural state in the United States, but its larger agricultural counties are in arid zones. Agriculture accounted for 80 percent of the water consumed in California in normal years in the 1980s (27 MAF (million acre foot) out of 34.5 MAF, CDWR, 1991). The physical system of mining, storage, and transportation has not changed much since the 1960s when the two major projects, the State Water Project (SWP) and the Central Valley Project (CVP), were added to existing surface water projects in the state. The California water system has significant water storage capacity that allows it to adjust to short-term shortages, but the drought of 1987-1991 tested the system. In the years, 1987-1991, statewide runoff was 48 percent, 48 percent, 70 percent, 48 percent, and 43 percent of normal runoff, respectively; and by summer, 1991, the CVP major reservoirs held less than 50 percent of their storage capacity of 25 MAF. This severe drought led to the changes that will be reported below.

The analysis in this paper relies on results from a variety of studies, but most of the results were drawn from two surveys conducted in the summer of 1991. Questionnaires were distributed to all California water districts and irrigation equipment dealers. Responses at various degrees of details were received from 135 water districts (70 percent of the districts) covering 85 percent of the irrigated land in California and 60 percent of the surface water used for irrigation. The dealer survey yielded 29 responses out of 45 contacts. Both surveys included responses to questions related to the period 1987-91. A more detailed description of the survey tools can be found in Zilberman et al. (1992).

Decisionmakers in an agricultural water system include managers of surface water reservoirs who decide about water releases at various periods; water district managers who set the prices and sell water to farmers; farmers, who use the water; and finally, water agencies that establish water allocation rules. We will analyze the response of each of these agents to the five-year drought in the following sections.

WATER SUPPLY DECISIONS

About two-thirds of the surface water used in California is allocated according to the Prior Appropriation Doctrine. The state and federal water projects account for one-third of the surface water, and they have junior rights relative to other surface water users. Water reservoirs managers control allocation of large inventories of surface water, and their choices should be consistent with inventory management under uncertainty since precipitation varies from year to year. Principles of inventory management suggest that annual water releases should depend on the stock of water in the reservoir rather than the actual annual precipitation. Thus, in the case of a drought, which lasts several years, deliveries of water from a reservoir will decline as the drought progresses.

Figure 1 shows that water stocks declined during the first few years of the California drought. Water stock declined by about 50 percent at the end of the second year of the drought to around 15 million AF. Table 1 shows that, even though the drought started in 1987, significant reductions in deliveries to water districts occurred only in the fourth year of the drought, 1990, and even larger reductions occurred in 1991. The reduction affected mostly contractors of the federal and state water projects who have relatively junior water rights compared to other surface water users.

We will use a generic term, water district, to refer to the different types of organizations that buy and sell water. It is reasonable to assume that they do not pursue profits but rather provide a service and aim to cover their costs. It is also reasonable to assume that they have relatively high fixed costs. Thus, as water districts receive less supply during a drought, they may increase user fees and water prices. Water districts may also replace some of the lost surface water supply by pumping ground water and by reducing conveyance losses through lining canals.

The results of the water district survey show that, indeed, during the drought, about 50 percent of the responding districts changed water pricing, with a higher percentage in southern regions, where there was greater scarcity. Additionally, 11 percent of the responding districts lined their canals and 12 percent installed pressurized pipelines after 1987. Districts in the San Joaquin and Fresno counties in the Central Valley faced particularly severe cutbacks in water availability. As a result, the largest number of water districts in these regions changed their water allocation rules, 69 percent of the districts in San Joaquin and 57 percent in Fresno, against the statewide average of 53 percent. The drought also led the districts to offer assistance to growers for irrigation scheduling (45 percent) and subsidized loan programs for changing their irrigation methods (39 percent).

FARMERS WATER CHOICES

Economic considerations suggest that, ceteris paribus, reduction in water supply and increased water prices will lead farmers to increase their reliance on ground water, adopt water-conserving technology, reduce water use per acre, move away from water-intensive crops, and fallow land (Dinar & Zilberman, 1991). The intensity of these responses is likely to increase as the drought progresses and water supplies decline.

The observed behavior is consistent with the above predictions. Figure 1 shows a continuous increase in the number of wells throughout the drought and an inverse correlation between water stocks in reservoirs and number of wells drilled. Values in Table 1 demonstrate the increase in ground water pumped in the central and southern San Joaquin regions, during the later years of the drought when surface water deliveries declined. The water district surveys show that both districts and farmers contributed to this increase. **The irrigation dealer survey shows a 25 percent annual increase in the sale of pumps during the drought.**

A historical perspective is useful for assessing the changes in irrigation practices that occurred during the drought. According to Casterline, Dinar, and Zilberman (1989) sprinkler irrigation was introduced in California during the late 1940s and low volume irrigation (LVI) systems, including drip and micro sprinkler were introduced in 1970. The diffusion of these technologies in the pre-drought period, 1982-1986, was rather slow and in 1985 sprinkler irrigation was used on 25 percent of irrigated land in California. These technologies were adopted mostly on locations with sandy soils, uneven topography, relatively expensive water, and, in the case of LVI, for tree crops.

As Figure 2 demonstrates, there was a significant increase in the use of LVI during the drought. Between 1987 to 1991, LVI replaced sprinkler irrigation for different categories of tree fruits and increased its land share to .6 in citrus, .4 in fruits and nuts, and .3 in grapes. LVI was also introduced in major vegetable crops, such as tomatoes for processing, and lettuce. Sprinkler irrigation significantly replaced furrow in other vegetable crops and in cotton (the most important field crop in California). Thus, the drought intensified the adoption of irrigation technologies in crops that used them before and led to their adoption on crops normally grown with traditional irrigation methods.

This response supports the results of models analyzing investment decisions under uncertainty, where the benefits of irreversible investments are subject to random shocks (McDonald & Siegel, 1986) and firms have the option of delaying investments. Firms will invest only when the net benefits of investment exceed a positive critical value. This study confirms our expectation that random events such as a drought are likely to drive the net benefits of investments in irrigation technologies above the critical level and lead firms to undertake investments they would not have otherwise.

In the Westland water district (which suffered the largest water supply reductions) farmers who continued with furrow irrigation in that district reduced their per acre water use by more than ten percent without significant yield changes. The drought encouraged farmers to seek the advice of irrigation consultants or to use computer software for their irrigation scheduling. There was a dramatic increase in the use of the services of the California Irrigation Management Information System (CIMIS). From 1986 to 1991 the number of its users increased from 500 to 2000 (CDWR, 1993).

By 1991 surface water inventories were not sufficient to protect the farmers from the reduced precipitation, and ground water and conservation were not sufficient to offset reduced surface water supplies. Table 1 suggests that the drought led to an increase of more than 50 percent in the volume of acres fallowed in our sample.

Table 1 provides a quantitative assessment of the importance of various components in adjusting to the shortfall of water supplies in the last two years of the drought from the 1987-1989 levels. In 1991 the project contractors in our sample received 1.638 MAF less than the average deliveries in 1987-1989. About 30 percent of this shortfall was covered by increased ground water pumping (ground water pumping is undocumented so our analysis probably underestimates the amount of pumping). About five percent was covered by increased supply of nonproject water. Assuming that each acre foot of fallowed land released 3.5 AF of water, fallowing accounted for about another 30 percent of the shortfall. Thus, all other adjustment methods (new irrigation technologies, crop switching, conservation) accounted for the remaining 36.3 percent of the adjustments in 1991. These simple calculations suggest that when there were substantial reductions in project water supply, conservation, fallowing, and increased ground water pumping each accounted for 1/3 of the short-term adjustments.

INSTITUTIONAL CHANGES

Water has been allocated in California according to the prior appropriation system, which is a queuing system that discouraged trade and did not provide much incentive for conservation. The literature of the political economy of resources (Rausser & Zusman) indicates that beneficiaries from the status quo will stall attempts to introduce welfare-improving institutions, but these changes will occur at crisis situations when efficiency benefits from reform are more significant and apparent. Thus, as the drought progresses, political economic argumentation suggests growing pressure for institutional changes, such as the introduction of water trading and marginal cost pricing of water.

The establishment of the California Drought Water Bank is a major institutional breakthrough, with the state approving and administering water trading. In 1991, it purchased 825,000 AF of water and sold 435,000 AF of water. The purchase price was $125 per AF, and the selling price was $175 per AF at the Delta. To supply this water, 166,000 acres of agricultural land were fallowed. Howitt et al., (1992) show that the water bank provided substantial overall economic welfare gain to the state and Dixon et al. show that the third-party effects of the water bank were modest. Another example of institutional change is the Central Valley Improvement Act of 1992 (also known as the Bradley-Miller Bill), which legislated the reallocation of 800,000 AF of water annually from the Central Valley Project for environmental purposes. It also allows the Bureau of Reclamation contracts to sell their water under certain conditions.

Seven water districts introduced tiered pricing to provide farmers with incentives to conserve water. Tiered water pricing is essentially inverse block pricing in which an initial volume of water, based on some historical level of use, is sold at a given price; and water purchased above and beyond the historical level is sold at a significantly higher price. Other districts introduced buy-back programs. Under these programs, farmers are paid a certain amount not to consume all of their entitled water.

These examples illustrate that the drought led decisionmakers at all levels to introduce mechanisms that rely on market forces and financial incentives to enhance conservation of water.

CONCLUSIONS

This paper shows the capability of economics to explain some of the behavioral outcomes that are associated with the recent California drought. In particular, (1) prices and scarcities affect water choices. As the drought becomes more severe, farmers increasingly adopt water conservation technologies, fallow land with relatively low-value crops, and increase ground water pumping. (2) There are gains from storage. The water reservoir system in California enabled its agriculture to survive three years of drought with minimal impact. With storage, the severity of the drought is not dependent on water flow but on water stocks. Of course, more detailed study is needed to quantify these results.

The results suggest that neoclassical microeconomic models were able to detect correctly the direction of change that will occur as water prices and scarcity increase. But in the case of both water technologies and institutions, we have not observed much adjustment in response to continuous minor changes in prices and scarcity conditions but, rather, a substantial change in response to a drastic event. So much of our static modeling is better in predicting direction of change than it's timing.

For years, economists recommended a transition toward water markets and were frustrated by the lack of change in the system. However, the height of the drought led to the introduction of officially approved water trading in California (though only for one year), which is the first step toward introduction of markets. We are convinced that the economic work on California water provided the foundation for the introduction of markets even though it could not predict its timing. Thus, the availability of a beneficial new technology or institutional design is not sufficient to assure their adoption. The paper suggests that extreme events trigger technological and institutional changes.

There are other examples where the timing of technological change was affected by large random shocks. The design for the tomato harvester was available 30 years before it was commercially adopted after the Bracero program was canceled in 1965. The massive introduction of center pivot irrigation in the plains was associated with the boom in agricultural commodity prices in the early 1970s, where prices reached a new high. Many of the most important institutional changes affecting U. S. agriculture have been the results of extreme events, such as the depression and the dust bowls of the 1930s. We should emphasize the development of modeling frameworks that are more capable of predicting the timing of major changes, and more attention should be given to study the impact of extreme events on institutional and technological changes.

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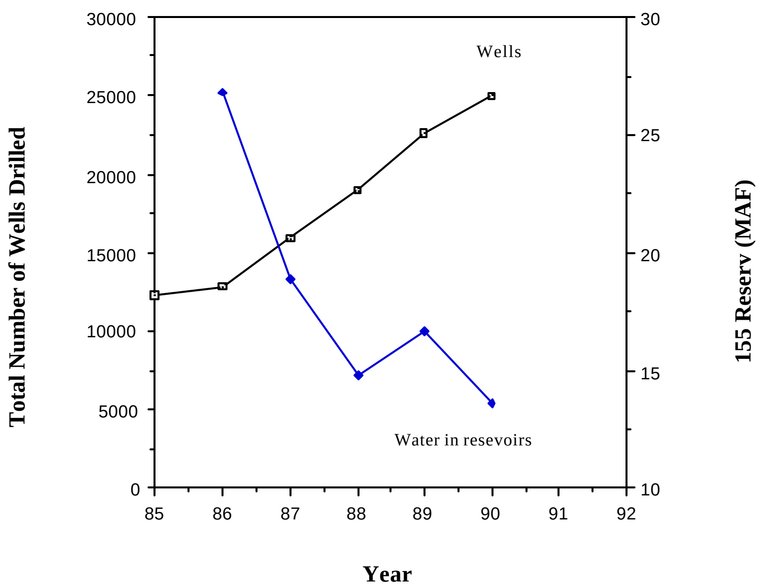

Figure 1: Water in Reservoirs and Wells Drilled during the 1987-1992 Drought

Figure 2: Use of Drip Irrigation on Selected Crops, 1987-1991

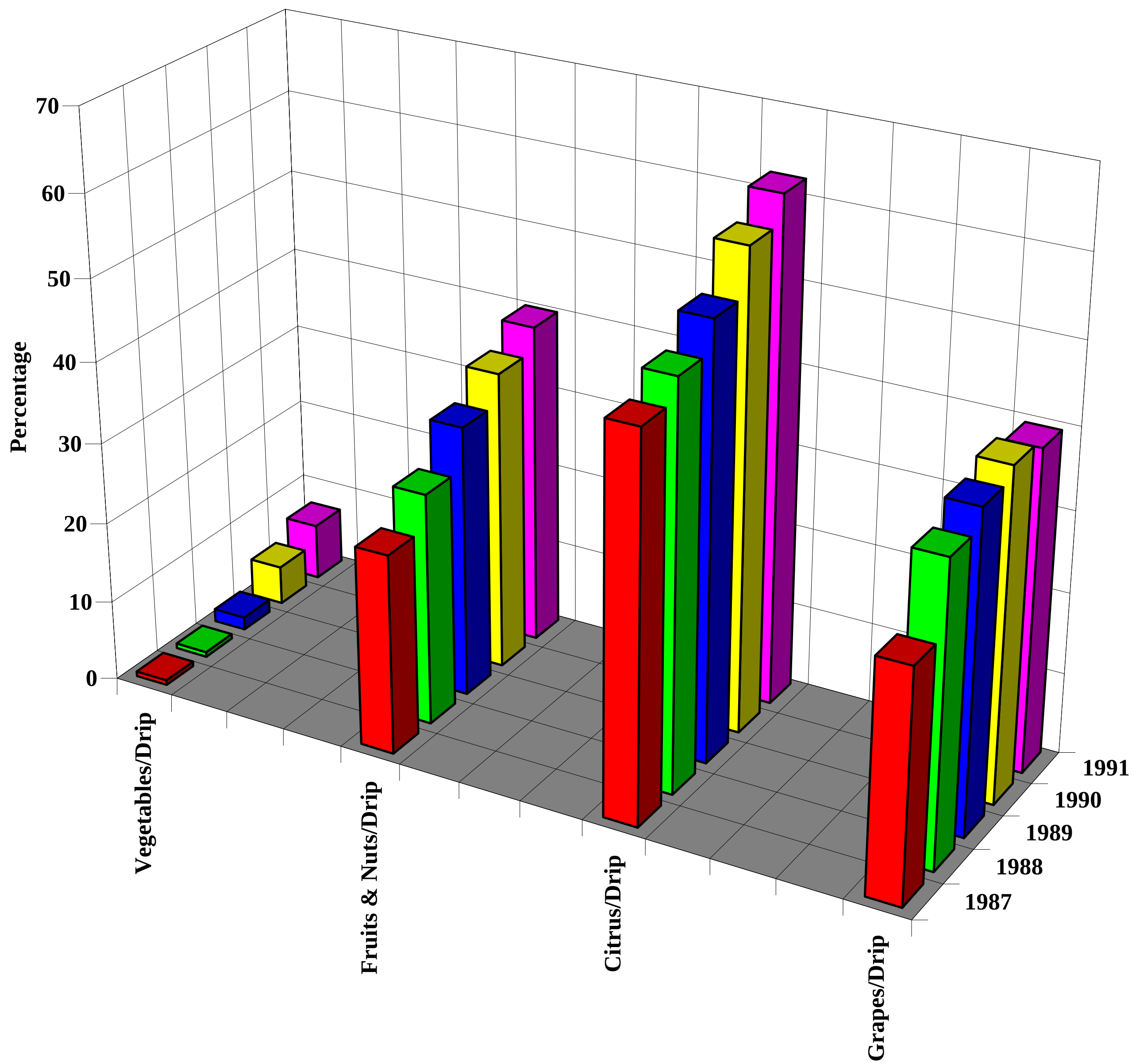

Table 1: Water Sources and Fallowed Acreage 1987-1991

	Project water	Nonproject water	Ground water pumped	Acreage fallowed
		(thousands of acre feet)	(thousands of acres)	
	Northern San Joaquin			
1987	1,112	2,086	199	117
1988	1,087	1,653	*324	117
1989	1,128	2,048	140	102
1990	962	1,903	164	104
1991	846	1,613	198	157
	Central and Southern San Joaquin			
1987	1,818	411	189	109
1988	1,787	198	186	119
1989	1,954	335	196	148
1990	1,372	203	388	129
1991	511	436	677	211
	All Other Regions			
1987	258	5,482	36	34
1988	289	5,879	22	28
1989	300	6,047	27	26
1990	307	6,126	39	25
1991	249	6,071	48	30
	TOTAL			
1987	3,188	7,980	425	259
1988	3,163	7,730	532	264
1989	3,382	8,430	363	276
1990	2,641	8,248	592	258
1991	1,606	8,120	923	397

Table 2: Adjustments to Supply Reductions by Project Contractors, 1990-91

	Project water	Nonproject water	Ground-water pumped	Acres fallowed @3.5 AF per acre	Water saving by fallowing	Effect of conser-vation methods
	(thousands of acre feet)		(thousands of acres)			
Averages 1987-89	3244	8046	440	266		
1990 shortfalls	603	(202)	(152)	(8)	(28)	(221)
1991 shortfalls	1638	(73)	(483)	(131)	(458.5)	(492.5)

*One water district drastically increased amount of ground water pumped this year because appropriative source was reduced.