Determinants of Water Sales During Droughts: Evidence from Rice Farm-Level Data in California

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Abstract: We estimate the effect of drought and opportunity to sell water to state-managed Drought Water Banks, on land fallowing patterns of rice farmers in three private surface water irrigation districts in Northern California. The analysis is based on 30 years (1984-2013) of spatial data derived from satellite data on fallowing decisions matched to highly detailed ownership data at the farm parcel level. We find that drought episodes, and the presence of a Drought Water Bank increase fallowed area and the likelihood to fallow. We examine the effect of each Drought Water Bank separately, finding significant differences among them. We also find that some water sale restrictions imposed by local or state authorities have significantly affected land fallowing. These findings have ramifications for water management in future California droughts.

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1. Introduction

Irrigated agriculture has a major share in total human water use, laying claim to more than 70% of surface water in the Western United States and 84% in California (Howitt and Sunding, 2011). In drought years, other users of water, such as municipal or environmental, often look to farmers to temporarily reduce or alter agricultural production on their fields and sell their water allotment to interested buyers. Such temporary water transfers, or water sales, from relatively water-abundant to water-short areas have become an important policy tool to cope with drought conditions (Easter and Huang, 2014).

California is one of the first states in the US that experimented with large-scale transfers of water. The expansive hydraulic infrastructure of dams, pumps and canals of the State Water Project and the Central Valley Project have moved large volumes of water around the state, often across different basins, increasing water system flexibility and allowing water to be used where it was needed the most (Reisner, 1993; Fairbanks, 2011). This infrastructure facilitates water trades during droughts. In the two recent major droughts of 1987-1992 and 2007-2009 California's Department of Water Resources (DWR) managed Drought Water Banks (DWB) as clearinghouses that pooled surface water from willing sellers and sold supplies to buyers facing critical demands in the southern half of the state (Israel and Lund, 1995; Howitt and Lund 1999; Clifford et al. 2004). Water trades across basins occur every year, but its activity increases in dry years. According to the most recent estimates, water markets account for about five percent of all water used annually by Californians, which is about 2 million acre-feet of water and if current trends continue it is likely that some cropland will be permanently retired (Hanak and Stryjewski, 2012).

One of the most common ways for farmers to sell water is to fallow their land, i.e., not cultivate for one season. Water trades are voluntary, i.e., farmers can choose to participate, fallow land and relinquish their surface water deliveries in exchange for a compensation for their water allocation. But to date there has been no analysis of farmer-parcel level trends and determinants of land fallowing, and related surface water sales. As farmers become water sellers their land use decisions may change and these changes in turn can have important local economic, environmental, and political effects.

The goal of this paper is to understand how California's water management policies, especially the Drought Water Banks, have affected individual farmers' land use decisions. In particular, this paper examines California rice farmers as medium grain rice is a particularly large water user and 96% of California rice is grown in the Sacramento Valley (Figure 1) where greater than 85% of California's surface water needs are acquired for users in the south (Hill et al., 2006; Fairbanks, 2011). The opportunity to sell water in a dry year can serve as a strong incentive to conserve water on low value production. For this reason, water markets have been argued to increase allocative efficiency of water (Dinar and Letey, 1991; Olmstead, 2010). But how precisely do farmers respond to water markets? Do they increase the fraction of fallowed land and continue farming on the rest of the farm (changes along the intensive margin)? Or do they completely stop production for a year (changes along the extensive margin)? Given that land fallowing can be a normal farming practice to restore soil fertility at lest for some crop types (not necessarily rice), is there a difference in fallowing decisions in a dry year without a DWB to a dry year that does not have an operational DWB? In other words, what is the effect of the opportunity to sell water on land use decisions of farmers?

These are important policy questions because rural communities are often anxious about the negative economic and environmental effects of water sales from their regions. The aggregate and cumulative effects of these transfers can have important watershed or community-level economic and environmental effects (Rosegrant and Ringler, 2000; Howe and Goemans, 2003; Ghimire and Griffin, 2014). As Hanak (2003; 2005) has documented, several rural counties in California have placed restrictions on water sales (in particular groundwater) from their counties in an effort to protect themselves from economic and environmental harm. We also investigate the effect of such state and county-level restrictions on rice farmers' land fallowing decisions.

2. Land Fallowing and Water Markets in California

A farmers' decision to fallow land i.e. not cultivate for one or more seasons, can improve or restore soil fertility (referred to as soil-resting) and can have positive externalities beyond the farm for watershed protection and runoff management. For example, summer fallow is used to conserve water on 20 million hectares of US cropland in the rain-fed wheat production systems of the Great Plains, Pacific Northwest, and Rocky Mountain regions (Sperow et al., 2003). Positive externalities are often a reason for public policies designed to incentivize land fallowing.[1] In California, however, thanks to the extensive hydraulic infrastructure and growing trades between water users, a unique nexus has emerged between agricultural land use in large private irrigation districts and statewide water management policy with regards fallowing.

In California, fallowing agricultural land is one of the most common ways farmers can sell water, or lease their water rights. Other means include excess water stored in surface reservoirs to which the seller has rights or other excess amounts of surface water that the seller has the right-to-use, but does not need and cannot store. As a result of either land fallowing, "conserved" surface water that the seller saves by reducing his or her own use, or by accessing groundwater supplies, water is transferred.

The economics literature analyzing farmer-parcel level decision making in land fallowing has focused on the case of farmers in developing countries where there is a high dependency on agriculture as a source of income and local food supply for the rural population and issues under study are about security of land tenure, poverty and/or incompleteness of credit, or insurance markets (see for example Goldstein and Udry, 2012). Usually this literature employs detailed farmer-household data sets to understand the incentives and constraints for land fallowing. Unfortunately, such detailed farmer-parcel level data sets are not available for the US. Analyses of water transfers in the US rely on county-level or basin system-level data. For example, Hanak (2003; 2014) compiled California county-level data to understand the determinants of groundwater export restrictions. In addition, efforts have focused on analyzing system-wide optimization models (Howitt and Lund, 1999), or input-output models like IMPLAN to study regional economic effects (Dixon et al., 1993; Howitt et al., 2014), and drainage

[1] Although recent research in the Midwest has suggested that reducing land fallowing might increase carbon sequestration potential of land (Sperow et al. 2003).

basin and/or county-level accounts recorded by state water agencies. A recent exception at a slightly finer scale, however, by Ghimire and Griffin (2015) compared surface water transfers from farmers located in irrigation districts to those not in irrigation districts in Texas. Our approach is even more fine-grained than Hanak's (2003), Howitt et al. (2014), or Ghimire and Griffin (2015) in that we study decisions to plant or fallow in farmers' individual fields within a tenure parcel in response to climate conditions and policy changes.

One explanation for the lack of farm-level or irrigation district-level analyses could be the lack of data. As Griffin (2012) discusses, in 1978 the *Census of Irrigation Organizations*, which used to be a part of the regular countywide Census of Agriculture (USDA) was terminated. While the potential of irrigation organizations in reallocating water from agriculture to urban or environmental uses captured significant academic attention during the 1980s and 90s surge of water marketing studies, interest seems to have waned, perhaps due in part to deficient statistical information regarding the overall command of water by irrigation organizations.

California experienced a long period of drought between 1987 and 1992.[2] In 1991 and then again in 1992, the California state government set up DWBs to facilitate the allocation of water. These DWBs were significant in that they were the first large water transfer programs in the US set up and run by a state government. In both 1991 and 1992, California's DWR served as a broker for water transfers. The next DWB was set up in 1994 and the most recent case was in 2009. Following the 2009 DWB, many water transfer stakeholders requested DWR to negotiate their own water purchases for increased flexibility and that DWR and federal Bureau of Reclamation (for the Central Valley Project) only facilitate water transfers but not operate a DWB in 2010. The nature of water markets is evolving, from active state participation to state's role being reduced to a facilitator and conveyor.

Each DWB was different in its operational details (Table 1). For example, in the 1991 DWB about half of the water came from farmers who fallowed their land and sold the water to the DWB. One-third of the water came from farmers who sold their surface water rights to the DWB but substituted with groundwater rights to continue farming. The remaining water for the DWB came from surface water supplies in Northern California that had excess water. In later DWBs, however, water was not bought via land fallowing contracts, but by other means such as stored excess surface water and groundwater substitution, which may still influence land fallowing decisions within an irrigation district (Dziegielewski et al., 1993). Moreover, as water transfers have become more decentralized, with the state acting as a facilitator/conveyor rather than a broker, there are now more restrictions and stipulations by counties of water origin or the state that have increased scrutiny on water sale decisions. For example, in order to minimize local economic effects from water sales, the DWR in 2008 mandated that no more than 20% of agricultural land in a county can be fallowed. In this current study, we put together a novel framer parcel-level data set to investigate the marginal effect of State policy (DWB) or local policy (groundwater export restriction) on the land fallowing decisions of rice farmers from a major water source region, Sacramento Valley, over a 30-year time span (1984-2013).

[2] See Hanak (2015) for an excellent review of Drought Water Banks and other water transfers in California.

3. Conceptual Framework and Empirical Specification

Assuming a profit-maximizing rice farmer, the decision to fallow or grow is based on a comparison of profits from agricultural production to the benefits of fallowing. All else being equal: we expect that fallowing in a dry year will be higher than in a wet year; DWR brokering the sales, and reducing transactions costs will increase fallowing but higher price of agricultural output (rice) will reduce fallowing; and furthermore, we expect that presence of a DWB, when rice farmers are compensated for relinquishing their water allocation, is associated with an increase in land fallowing.

If there are no fixed costs with the decision to grow or fallow, or any other constraints on area fallowed, a farmer could fallow any fraction of the parcel between 0 and 1 in order to maximize profits on the intensive margin. But if there are fixed costs associated with production and fallowing decisions, we may not actually observe all possible fallow fractions between 0 and 1, but a concentration of fallowing fraction around certain values where farmers are able to minimize short term losses due to forgone production. Fixed costs may include paperwork with the irrigation district, the management of labor, equipment investment loan payments (typical California rice farmer's investment is $1250 ha^{-1}; Hill et al., 2006), aerial seeding, fertilizers/pesticides, or other input contracts if the farmer decides to forego production. In order to allow for the effects of fixed costs we construct two different variables to measure land use behavior and estimate the effect of DWB on each of them separately as follows:

$$F_{it} = \beta_0 + \beta_1 DWB_t + \beta_2 D_t + \gamma_k R_k + \beta_3 P_{t-1} + \beta_4 t + \eta_i + e_{it} \tag{1}$$

where F_{it} denotes the status of land use of parcel i in year t. It can take one of two forms:

(i) Fraction of parcel i fallowed, or

(ii) Fallow status of parcel i; if any fraction is fallowed, fallow status is 1, and 0 otherwise.

In (i) F_{it} is a continuous variable between 0 and 1, and in (ii), F_{it} is a dummy variable that takes a value of 0 or 1. The former allows us to explore the effect of explanatory variables on the intensive margin of farming and the latter allows us to explore the effect on the extensive margin. Explanatory variables include, D_t a dummy variable that takes a value of 1 if the year t was a drought year, DWB_t is a dummy variable that takes a value of 1 if in year t a Drought Water Bank was instituted by the DWR. R_{kt} denotes a water sale restriction, that take a value of 1 for years when such a restriction k was in effect, and 0 otherwise, P_{t-1} is the price of rice at the time of planting, t is the time trend and η_i are parcel fixed effects. Rice planting in California is undertaken by April, after D_t is determined on the basis of precipitation as of October of previous year. But the price of rice is determined after planting, so we use the previous year's rice price, P_{t-1} as an explanatory variable in explaining farmers' decision to plant in t.

We use panel fixed effects to estimate (1) when F_{it} is fraction of parcel fallowed, and a panel logit model when F_{it} denotes the fallow status. Fixed effect results are efficient, and preferred to a random effects regression, despite the loss in degrees of freedom, and that the coefficients of η_i cannot be estimated (Baltagi, 2005).

We hypothesize that β_1 is positive. When the dependent variable is fallow fraction, β_1 estimates the effect of DWB on average fraction of land fallowed. When the dependent variable is dummy variable, β_1 estimates the effect of the existence of DWB on the likelihood of fallowing. We hypothesize that: β_2 is positive, i.e., fallowing is greater in drought years than in non-drought years; γ_k is negative, indicting that a water sale restriction is associated with an increase the transaction costs of water sales and therefore reduces fallowing; β_3 is negative, indicating that higher price of rice is associated with a reduction in fallowing.[3]

We also explore the effect of parcels' time-invariant attributes by allowing for heterogeneous fixed effects for parcel area (A_i) and irrigation district (ID_i).

$$F_{it} = \beta_0 + \beta_1 DWB_t + \beta_2 D_t + \gamma_k R_k + \beta_3 P_{t-1} + \beta_4 t + \beta_5 (DWB_t \times A_i) + \beta_6 (DWB_t \times ID_i) + \eta_i + e_{it} \quad (2)$$

where β_5 estimates the effect of parcel area, and β_6 estimates the effect of *ith* irrigation district on fallowing behavior in drought water bank years.

4. Data

4.1. Study Area

We chose three private irrigation districts located in Butte County within the Sacramento Valley (Figure 1): Western Canal, Richvale, and Biggs-West Gridley irrigation districts (Figure 2). The Sacramento Valley is part of a relatively large and diverse hydrologic basin of approximately 17,297,377 acres. Butte County is the originating county of the State Water Project, home to the Oroville Reservoir, which provides surface water to the California aqueduct, and to all three irrigation districts in this study. Western Canal is the second-largest private irrigation district in the Sacramento basin. All three irrigation districts comprise 48% of total irrigated acreage in Butte County. Our sample encompasses 78% of all area in the three irrigation districts and about 88% of all rice growing area in Butte County.[4]

The sample districts nearly exclusively grow medium grain rice *(Oryza sativa;* Hill et al. 2006) and have senior appropriative water rights ("first in time, first in right") that pre-date 1914 (established in the California Civil Code in 1872 ending in 1914; Water Commission Act of 1914). Typically, water right for a farmer ('water duty') in these irrigation districts is 4.2-5.5 acre-feet per acre. Cost of water to each district farmer is

[3] The explanatory variables, such as drought or existence of DWB, can be thought of as a state of nature, which although clearly exogenous to parcel behavior, cannot tell us the causal effect of that variable. All rice farmers in our sample were exposed to the same state of nature at the same time. If the coefficient of DWB dummy is significant, for example, arguably it could be capturing the effect of another confounding event. So, the coefficients cannot be interpreted as causal impacts of respective variables.
[4] 31% of Western Canal lies in neighboring Glenn County, which is excluded from this analysis.

$30-$47/acre of rice, which is meant to cover the cost of water delivery and operation/maintenance of delivery infrastructure.[5] Having pre-1914 water rights means that even in drought years farmers in these irrigation districts have less uncertainty of receiving their full water allocations. Water deliveries, however, can be curtailed if, as required by the 1963 State Water Project agreement with the Feather River farmers (as they are collectively known), on April 1st of each year the DWR determines that Oroville Reservoir is receiving less than 600,000 ft^3/sec from the Feather River (California Department of Water Resources). This curtailment is triggered only in extreme dry weather. For example, in 2014, while California was experiencing the worst drought in the last 1,200 years (Griffin and Anchukaitis, 2014) irrigation districts in Butte County received their full water rights and sold their water allocations (Hacking, 2014). But in 2015, due to continuing drought, the water supplies have been reduced by up to 50%. This is only the second time in the last 24 years this has occurred. As a result the farmers decided to not transfer water from the districts.[6]

4.2. Data Collection

We compiled in a geographical information system (GIS) database of all publicly available data covering the three irrigation districts. These include detailed spatial tax parcel data, DWR land use survey data, and historical satellite data detailing the rice plots covering the years 1984-2013.

The historical rice field location data was available from DWR's land use surveys program for 1994, 1999, and 2004. These field maps were used with Landsat TM 30m resolution imagery to help identify growing rice and fallow rice fields. All cloud free Landsat TM scenes available for the months of July and/or August for each year from 1984-2013 was acquired from the US Geological Survey's Eros Data Center with level 1 geometric processing.[7] Each year's satellite image was used as a screen backdrop in the GIS to which the DWR rice fields were overlaid to manually identify rice fields that were fallowed in that year, if the field was only partially fallow as the paddy dikes were adjusted then the field was re-digitized to reflect the partial fallow percentage. [8] The identification of fallow rice fields is very simple as the contrast between growing rice fields and those that are bare soil is very apparent to a trained satellite imagery interpreter.[9]

[5] Personal communication of authors with irrigation district managers (date: 03/11/2015)

[6] To be precise, the board of directors of each irrigation district decides to participate in water transfers (with or without a DWB) and then the individual frames within the irrigation district can elect to fallow their field.

[7] The imagery was composited using bands 1-5 and 7, and then displayed as a RGB 435 band combination (Near IR, Red, Mid-IR) for maximum differentiation and interpretation of healthy rice vegetation (Nuarsa et al., 2005; Jensen, 2007) versus fallow bare soil land.

[8] The rice-growing season in California starts in April/May and ends in late September/early October for harvest. The months of July and August present the maximum growth and flowering period of the rice plant. Rice land coverage changes during the rice life sequence as follows in flood irrigated rice fields: almost all land coverage is dominated by water during the plantation period (May-June), with age rice vegetation coverage grows and reaches a maximum (July-August) and then gradually decreases until harvest time (September-October) (Nuarsa et al., 2007).

[9] Any rice fields in any year that required spatial editing in the form of adding or removing boundaries was conducted on screen with the help of the Landsat TM imagery as the DWR land surveys were only

Next, all rice fields (non-fallow and fallow; ~6103 fields) for each year were separately spatially unioned with Butte County's tax parcel database for only the area included in the three irrigation districts (~2680 tax parcels). Historic GIS versions of the tax parcel database were acquired for 2001 and 2013. Because no earlier GIS tax parcel databases existed we made the assumption based on a comparison between 2001 and 2011 that over the study period the tax parcel boundaries of the farms had changed minimally (i.e., only two small parcel splits identified between 2001 and 2013), showing us that the spatial tenure boundaries of the rice farming lands were most likely fairly constant over the study time period.[10] The tax parcel database allowed us to merge rice fields into parcels. A parcel is a contiguous agricultural area owned by a unique owner in our sample. This allowed us to examine the decision-making from the landowners' perspective. In this way, we compiled a sample of 780 farm parcels, each under a unique owner, each of which was observed for 30 years. Rice is the primary crop grown on these acres and our data includes information on rice planting for each year in the period 1984-2013.[11]

The data collected were verified as best as possible via conversations with the irrigation district managers, who shared their records for total acres fallowed and volume of water transferred in recent years when they participated in transfers. Fallow acreage detected from satellite data and reported acreage from managers were off by 2-4%, which is a tolerable margin of error.

Finally, California's Department of Water Resources classifies all water years (October to September) into five "year-types": Critically Dry, Dry, Below Normal, Above Normal and Wet. We collected water year classifications on all years 1984-2013 from Department of Water Resource website. Furthermore, we obtained price of rice (all medium grain varieties) from annual Crop Reports from Butte County's Department of Agriculture website.

4.3. Construction of Variables

Table 2 shows the average parcel size in each irrigation district: 115 acres for Biggs-West Gridley Irrigation District, 102 acres for Richvale Irrigation District, and 160 acres for Western Canal Irrigation District. Total acreage of sample parcels is 97,147 acres, of which 24,209 acres lie in Biggs-West Gridley Irrigation District, 31,872 acres lie in

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conducted every five years and some rice fields had changed shape between surveys, but this was found to be minimal across all years.

[10] The owner, however, did change over time, though not greatly (less than one percent), so the assessor parcel numbers were checked with the county tax assessor's office to confirm and update the tax parcel database for each year. In general, the attribute data contained within the tax parcel databases provide owner type (i.e., individual, LLC, corporation, etc.) and residency information (i.e., county and state of residence), land values, improved land values, and number of structures on the property. In addition, GIS data layers consisting of water conveyance canals to support each irrigation district, roads, railroad, grain silos, walnut/peach/plum orchards, and soil types have been developed as part of the database.

[11] Of the 69% of Western Canal in Butte County, 9.6% of the district is natural vegetation (5.7%), urban (1.3%), and agriculture land-use types (2.6%) other than rice. Richvale is completely contained in Butte County with 21% of the district covered in vegetation (19%), urban (1.7%), and other agriculture land-use types (0.3%) other than rice. Biggs-West Gridley is completely contained in Butte County with 30.5% of the district covered in vegetation (17%), urban (2.9%), and agriculture land-use types (10.6%) other than rice. The other agriculture types represent orchards and diary, which do not have fallowing as an option.

Richvale Irrigation District and 41,065 acres lie in Western Canal Irrigation District.

Fallow Fraction and Fallow Status

Fraction fallowed varied between 0 and 100%. On average 12% (i.e., about 15 acres) is fallowed in a given year. Figure 3 shows the count of parcels fallowed and not and Figure 4 shows the average fraction of parcels fallowed for each irrigation district.

Drought

We assign the drought dummy D_t a value of 1 for each year declared as 'dry' or 'critically dry', by the DWR, and 0 for all other years. These include: 1985, 1987-1992, 1994, 2001-2002, 2007-2009, and 2012-2013. These are 11 out of 30 years in the sample.

Drought Water Bank

Although districts and their willing farmers may engage in water transfers in any year, a DWB announcing state facilitated water purchases before rice planting season started was in effect four times between 1984-2013: 1991, 1992, 1994 and 2009. We assign the DWB dummy value of 1 for these 4 years, and 0 for all other years. There are 7 drought years when there was DWB not in effect.

Water Sale Restrictions

Since the first DWB in 1991, there has been an increase in county or state-level regulations for selling and buying water, which may have increased transaction costs for water trades. We consider three such restrictions:

(i) Groundwater Export and Substitution Restriction: In 1996, Butte County restricted transfers of groundwater outside of the county, or transfers of surface water made on the basis of groundwater substitution (Butte County Department of Water and Resource Conservation). Both need a permit from the County government, which is a time-consuming process. This ordinance was part of a broader movement in rural California to protect local groundwater resources from excessive pumping (Hanak, 2003). This county ordinance effectively increased transactions costs for water transfers (Howitt, 2014). As expected, this ordinance, if effective, can reduce the incentive to fallow. We create *Groundwater Restriction Dummy* by assigning a value of 1 to all years after 1996.[12]

(ii) Fallow Acreage Restriction: Since 2008, farmers are not permitted to fallow more than 20 percent of cropland in a county to limit local economic effects of water sales.

[12] In November 1996, Butte County voters approved a groundwater conservation ordinance, known as measure G, intended to provide groundwater conservation through local regulation of water transfers outside of the county with a groundwater component. Since 1996 a permit is now required from the county for both exportation of groundwater outside the county and groundwater pumping as a substitute for surface water exported outside the county. A permit for water transfer outside of the county would be denied if the proposed activity would: Cause or increase an overdraft of the groundwater underlying the county Bring about or increase saltwater intrusion; Exceed the safe yield of the aquifer or sub-basins underlying the county; Result in uncompensated injury to overlying groundwater users or other users; or Cause subsidence (Appendix D Butte County Code Chapter 33 Groundwater Conservation)

California's Department of Food and Agriculture reports a $260 million loss attributed to drought conditions.[13] We examine the effect of this restriction with *Fallow Acreage Restriction Dummy* by assigning a value of 1 for all years after 2008.

(iii) Contiguous Fallow Acreage Restriction: Rice and its supporting infrastructure of canals provides habitat for the giant garter snake, an endangered federally listed aquatic snake species. Halstead et al. (2013) suggest that preserving and restoring areas near historic marsh, and minimizing activities that reduce the extent of marsh or marsh-like (e.g., rice agriculture) habitats near historic marsh may be advantageous to giant garter snake survival. Since February 2010, farmers wishing to fallow land for transfers must limit fallowed area to 320 acres and surround these fields with rice cropped land to allow the giant garter snake a safe passage (California Department of Water Resources and U.S. Bureau of Reclamation, 2012). We create a *Contiguous Fallow Restriction Dummy* by assigning all years in 2010 and afterwards a value of 1, and 0 for all other years.

<u>*Price of Rice*</u>

Price of all varieties of medium grain rice were obtained from annual Butte County Crop Reports, and adjusted for inflation.

4. Results

Table 3 shows the average behavior in land fallowing. If water availability is a binding constraint for rice production, we can expect that the average fallow fraction of a parcel in dry or critically dry years (14.4%) to be greater than the average fallow of a parcel in wet years (9.8%). An independent samples t-test shows that this difference is statistically significant ($p < 0.001$). Similarly, in a dry or critically dry year without a DWB, 11.5% of a parcel is fallowed but in a dry or critically dry year with DWB, 16.2% is fallowed. The difference between these averages is statistically significant ($p < 0.001$), indicating that even at the aggregate level, not just at the parcel-level, DWB increases fallowed area across all irrigation districts.

Figure 3 illustrates the number of parcels fallowed had a steep drop after 1993. Even though fallow count and total acreage fluctuated every year, it did not reach the pre-1993 levels. Figure 4 shows the movement in fallowing fractions in the three irrigation districts, showing that the farmers in neighboring irrigation districts are responding to similar pressures, but that fallow proportion in Biggs-West Gridley Irrigation District is almost never greater than those in the other two districts. Also, since 1993, fallow fraction has not exceeded 20 percent of area. In 2003, and 2010 Richvale ID fallowed 20 percent of its land but neither year was a ‘dry’ or a ‘critically dry’ year. Figure 4 shows that area fallowed fluctuates even in non-drought years. For example, comparing the period 1995-1999 to 2001-2002. The proportion fallowed peaks higher in drought years but it seems that there is always some fallowing going on.

Figure 5 plots the real price of rice, and we see the upswing in prices since the early 2000s, just as total acreage fallowed has dropped.

[13]Similar rules were created on the buyer side: the would-be buyers will have to demonstrate water conservation savings of at least 20% to qualify for purchasing water from the program.

Figure 6 shows the annual mean and standard deviation in fallow fraction in pooled data for all irrigation districts. The standard deviation in fraction fallowed seems to have increased since the year 2000.

Table 4 shows the results of a fixed effects regression of the model in equation (1). Column (1) shows the result of the fallowed fraction regressed on just the time trend, and then in columns (2) –(4) we add weather, rice price, and DWB dummies. The coefficient of the time trend variable is negative and significant indicating a declining trend in average percentage of parcel fallowed. Fallowed fraction has decreased in 1984-2013 by an average of about 0.7 to 1% of parcel area every year. This is surprising because the overall trend in water transfers in California shows an increase in the volume of water transferred as well as an increase in the number of transactions conducted (Brewer et al., 2008; Hanak and Stryjewski, 2012).

Does our result of reduction in fallowed area in Butte County contradict the state-level trend of increasing water sales? There are two possibilities regarding such a conclusion: One, farmers may be fallowing for other reasons (in the case of rice either for heavy re-laser leveling or for eradicating highly noxious weeds, although both are infrequent practices in this study area) and not selling water, and second, water may be sold while the farmer continues to grow with groundwater. The first possibility would mean that fallowing behavior would *over*estimate volume of surface water transferred, and the second possibility would mean that drawing a conclusion about volume transferred from land fallowed would *under*estimate the surface water transferred. We return to this issue of fallowing and volume of water sold later in the discussion.

Results in column (2), Table 4, show that when controlling for the time trend (which stays negative and significant regardless of specification), drought, indicated by a dry or critically dry year, has a significant and positive effect on fraction of land fallowed. Column (3) shows that the presence of a DWB also has a significant and positive effect on fraction of land fallowed. In a dry or critically dry year farmers fallow on average a 3.8% greater fraction of their parcels. When a DWB is operational and farmers can sell their surface water allocation they fallow an additional 1.8% of their land. These results indicate that DWBs strongly incentivize land fallowing, above and beyond the reasons of being in a dry year. In other words, fallowed fraction is significantly greater in DWB years, than in dry years without DWB. Price of rice somewhat dampens this effect; the coefficient on price is -2.4, i.e., a $1 increase in price/ton reduces fallow fraction by 2.4%. The coefficient of rice price is negative and significant in all specifications indicating, as we expected, that higher price of rice at the time of planting i.e. the price known in the previous year, would discourage fallowing even in drought or DWB years.

Column (4) in Table 4 disaggregates the DWB dummy into four separate dummy variables for each year a DWB was in operation. Interestingly, all DWBs do not have a positive effect on land fallowing; there was an increase in fallow fraction by about 12% in 1991, an increase in 7% in 1992 but the 1994 DWB was associated with a reduction in fraction fallowed, by about 12.5%. The most recent 2009 DWB had no significant effect on fraction fallowed. These differences in signs of the coefficients reflect the differences in the circumstances of each DWB. In 1994 farmers sold their surface water allocations and grew rice with groundwater. Table 1 shows that 85% groundwater substitution contracts were offered in 1994 DWB. Therefore we do not see an increase in fallow fraction in 1994. But this excessive groundwater pumping led to a drop in the water table and prompted the adoption of groundwater substitution and export restrictions by Butte County voters in 1996 (Hanak, 2003; Msangi and Howitt, 2006; Khokha, 2014). From Table 1 note that only 75,000 acre-feet are purchased by 2009 DWB, the lowest volume compared to its predecessors.

Table 5 presents the results of the fixed effects logit model on equation (1). The dependent variable is now the fallow dummy (a value of 1 if any fraction of parcel is fallowed, and 0 if the entire parcel is planted with rice). Column (1) shows that fewer parcels are fallowed over time, Column (2) shows that farmers are more likely to fallow some part of their parcel in a 'dry' or a 'critically dry' year and column (3) shows that the presence of a DWB on average, does not have a significant on the likelihood to fallow. In column (4) we disaggregate the DWB dummy for each DWB year, we find that 1991 and 1992 DWBs were associated with increase in fallow status of parcels, but 1994 DWB significantly reduced the likelihood to fallow. The 2009 DWB had an insignificant effect. As before, higher price of rice is associated with a reduction in the likelihood to fallow. These results suggest that the effects of weather, DWB and rice price are similar on the extensive and intensive margin of rice field fallowing.

In Tables 4 column (5) the results of water sale restriction dummies are presented. The coefficient of Groundwater Restriction Dummy (dummy variable equals 1 for $t > 1996$, and 0 otherwise) is positive and significant, i.e., since the passing of the groundwater export restriction ordinance the average fallow fraction has *increased*. This is a surprising result because we expected groundwater export and groundwater substitution restriction to dampen the motivation to fallow. In Table 5 column (5), however, the coefficient of Groundwater Restriction Dummy is negative and significant. Taken together these results indicate that since 1996, the likelihood that a farmer will fallow her rice fields has decreased, but the fraction of rice fields fallowed has increased. Farmers in the irrigation districts may have responded to groundwater export and substitution restriction by *increasing* fraction fallowed but not necessarily by deciding to fully fallow. This behavior could be partly explained by the permit process with the county government needed for groundwater substitutions as a fixed cost mentioned earlier.

The coefficients of Contiguous Fallow Restriction Dummy and Fallow Acreage Restriction Dummy are positive and significant in Tables 4 and 5, indicating that the timing of both restrictions is associated with an increase in the likelihood to fallow as well as fraction fallowed. The results also show similar effects along the intensive margin after 1996. These are puzzling results and need further research.

We now present Figures 7, 8 and 9 which present the above results visually. Each plots the frequency distribution of the difference in average fallow behavior of sample plots in two alternate states of nature, the dependent variable in equation (2). Figure 7 shows that the right skew to the distribution is an indication of higher number of parcels fallowed in dry years than in non-dry years. Figure 8 shows the same pattern for DWB. Figure 9 presents the effect of groundwater restriction. After 1996, when the groundwater export restriction was passed, most of the parcels do not fallow at all, but the average fallow fraction amongst those who fallow is significantly larger.

Table 7 presents the results of equation (2). Column 1 shows that Richvale irrigation district has the largest fallow fraction of all three irrigation districts: the coefficients of (DWB x BWG ID) and (DWB x WC ID) are both negative and significant. Size of the parcel has no significant effect on fallow fraction. Column (2) reports the results of the logit model. Western Canal parcels are less likely to fallow than both Biggs-West Gridley and Richvale (Richvale and Biggs-West Gridley are not statistically different). Also, larger parcels are less likely to fallow in a Drought Water Bank year. Taken together these results indicate that there are some important differences across irrigation districts as suggested by Griffin (2012), and while parcel size has no effect on fallow fraction, we notice that larger parcels are less likely to fallow. This may be due to differences in costs of fallowing, the fixed costs we mentioned earlier.

5. Discussion

In summary, our first result is that in the 30-year data, 1984-2013, 1) the average percentage fallowed of each parcel, as well as 2) the number of parcels fallowing any percentage area, are declining. This result is robust after controlling for weather, price of output (rice), presence of DWB, as well as parcel-level fixed effects. This result is also robust after dropping pre-1994 data when price of rice were lower. This result is surprising when juxtaposed with the state-level trend that 1) number of water transactions, and 2) the volume of water transferred via water markets are increasing in California. We propose that this decline could be partly explained by the increased local and state restrictions on water transfers and the higher price of rice.

Returning to the issue of whether the decline in fallowed land can be taken as evidence that the volume of water sold from these irrigation districts is decreasing. The connection between fallowing land and water sold is not so direct; non-fallowed acres could be using groundwater to irrigate and hence fallowed area may underestimate surface water conserved. Although since 1996 groundwater substitution has not been allowed by Butte County's Measure G Ordinance without a permit, and county records show that not even a single application for such transfer (groundwater substitution) has been filed (Butte County Department of Water and Resource Conservation, 2015). Assuming stable per acre use of water, i.e., no change in crop or irrigation technology (which in fact we do not observe in our data), and compliance with this policy, i.e., no farmer sold their surface water without filing a groundwater substitution permit, decrease in fallowed land can indeed be interpreted as decrease in volume of water sold. Even though transfers are increasing in all of California, the private Feather River irrigation districts in Butte County are reducing their area fallowed over the time period outlined in this study.

Our second main result is that higher price of rice has lowered fallowed area in all three irrigation districts, regardless of weather or presence of a DWB. This is in contrast to Hanak and Stryjewski (2012) who could not find a statistical correlation between rice prices and water trading in Sacramento Valley farmers, as Hanak (2015) reports.

Third, while fallowing is always going on, the State policy of Drought Water Banks significantly increased the proportion fallowed by an average of 4.7% per year. Presence of a DWB, even when fallowing contracts are not offered, increases the average land fallowing, although they do not significantly affect the likelihood to fallow. Although DWBs were associated with an increased likelihood to fallow and a greater fallow fraction, each successive DWB had a smaller effect. The 1991 and 1992 DWBs were associated with an increase in fallowing but 1994 DWB reversed the effect was not and 2009 had no effect.

Fourth, groundwater export restriction, from the county government, is associated with a strong decline in likelihood of fallowing but an increase in fallow fraction. Results for the effect of two other restrictions, both from the State, were associated with an increase in fallow fraction and likelihood to fallow. Either these restrictions are having opposite-to-intended effects, or our approach of modeling them needs to be reconsidered.

Fifth, there are significant differences across irrigation districts in fallowing behavior during DWB years. This points to the importance of differences in institutional structures of each ID, even though they may be similar in many other respects, which could affect whether and how it participates in water sales. Moreover, within irrigation districts, larger parcels tend to fallow less often in DWB years.

Sixth, while the average fallow area has declined, the standard deviation in fallow fraction within irrigation districts has increased.

6. Conclusions and Future Research

In this paper we analyzed 780 rice farm parcel level land use data in three private irrigation districts, comprising a total of 97,147 acres with senior water rights of ~900,000 acre-feet/year. Using parcel level spatial observations of land fallowing over 30 years, our objective was to understand the aggregate and parcel-level time trend in land fallowing and whether droughts and presence of DWBs or restriction for water trades had an effect on land fallowing.

While much is written about water transfers and distribution (Jenkins et al., 2001; Lund et al., 2008; Hanak, 2015), flow requirements for endangered species (Lund et al., 2008) and the water needs of the urban centers and agriculture south of the Sacramento River valley (Reisner, 1993; Glennon, 2010; Fairbanks, 2011), there is a notable lack of, yet a strong need for farm-level synthetic overviews of the determinants that guide producers decision during times of drought or non-drought. This is especially required for understanding farmer behavior in an area of water origin. The main contribution of this paper is that it presents an approach for parcel-level data compilation and analysis to understand land-fallowing trends in response to changing conditions. Especially as water transfers become more decentralized and the state serves as a facilitator and a conveyor of transfers rather than a broker, it will be important to understand the farmer or irrigation district level response to changing weather and local or state policies.

Next steps in this research would be to explore spatial distribution of fallowed parcels to understand the spatial patterns of fallowed land emerged from decentralized fallowing decisions and a deeper analysis of farmer level characteristics in relation to ownership type, owner location, and other land-use restrictions. The spatial patterns of fallowed land emerged from decentralized fallowing decisions can affect connectivity of habitat for threatened species. Also, groundwater recharge can be affected by the location of fallowed parcels.

This paper is a first step towards a context-based analysis of rice farmer parcel level data that included a large range of variability in the human-nature system from which stakeholders must derive decisions during drought and non-drought years. These agricultural and water use/transfer decisions are crucial to understanding the tensions and flexibility inherent in future land-use change dynamics as they pertain to rice production and the vulnerable hydrological system of the Sacramento River valley and California's State Water Project. Our study shows that collection and analysis of parcel level dynamics provides a bottom-up approach, which aggregated county level and basin studies are not able to articulate.

References:

Baltagi, B.H. (2005). *Econometric Analysis of Panel Data*. 3rd edition. John Wiley, New York, NY.

Brewer, J., Glennon, R.R., Ker, A., and Libecap G.D. (2008). Water markets in the west: prices, trading, and contractual flows. *Economic Inquiry*, 46(2), 91-112.

Butte County Department of Water and Resource Conservation (2015). Water Transfers. http://www.buttecounty.net/waterresourceconservation/Home.aspx Accessed February 25, 2015.

California Department of Water Resources (2015). Water Transfers Program. http://www.water.ca.gov/watertransfers/ Accessed February 25, 2015.

Dinar, A., and Letey, J., (1991). Agricultural water marketing, allocative efficiency, and drainage reduction. *Journal of Environmental Economics and Management*, 20, 210–223.

Dixon, L., Moore, N.Y., and Schechter, S.W. (1993). *California's 1991 Drought Water Bank*. Rand Corporation.

Dziegielewski, B., Garbharran, H.P., and Langowski, J.F. (1993). Lessons learned from the California Drought (1987-1992). National Study of Water Management During Drought, Institute for Water Resources, U.S. Army Corps of Engineers.

Fairbanks, D.H.K. (2011). *California Cultural Landscapes: An Exploration of Spatial Patterns Over Time*. 2nd edition, Kendall-Hunt Press, Dubuque, IA.

Ghimire, N. and Griffin, R.C. (2014). The water transfer effects of alternative irrigation institutions. *American Journal of Agricultural Economics*, 96(4), 970-990.

Glennon, R. (2010). *Unquenchable: Americas water crisis and what to do about it.* 2nd edition, Island Press, Covelo.

Goldstein, M., and Udry, C. (2008). The profits of power: Land rights and agricultural investment in Ghana. *Journal of Political Economy*, 116(6), 981-1022.

Griffin, D. and Anchukaitis, K.J. (2014). How unusual is the 2012-2014 California drough? *Geophysical Research Letters*, 41, 9017-9023.

Griffin, Ronald C. "Engaging Irrigation Organizations in Water Reallocation." Nat. Resources J. 52 (2012): 277.

Heather Hacking 'Feather River farmers receive full water supply, and plan water transfers Posted: 04/19/2014 04:11:41 PM PDT at http://www.chicoer.com/news/ci_25600416/feather-river-farmers-receive-full-water-supply-and Accessed Oct 21st 2014.

Halstead, B.J., Wylie, G.D., and Casazza, M.L. (2013). Ghost of habitat past: historic habitat affects the contemporary distribution of giant garter snakes in a modified landscape. *Animal Conservation*, 17(2), 144-153.

Hanak, E. (2003). *Who Should be Allowed to Sell Water in California? Third-Party Issues and the Water Market*. San Francisco, CA: Public Policy Institute of California.

Hanak, E. (2005). Stopping the Drain: Third-party Responses to California's Water Market. *Contemporary Economic Policy*, 23(1), 59-77.

Hanak, E. (2015). A California postcard: lessons for a maturing water market. in *Routledge Handbook of Water Economics*, K. Burnett, R. Howitt, J.A. Roumasset, and C.A. Wada (Eds.), Routledge.

Hanak, E. and Stryjewski, E. (2012). *California's Water Market, By the Numbers: Update 2012*. Public Policy Institute of California, San Francisco, CA.

Hill, J.E., Williams, J.F., Mutters, R.G., and Greer, C.A. (2006). The California rice cropping system: agronomic and natural resource issues for long-term sustainability. *Paddy and Water Environment*, 4, 13-19.

Howe, C.W. and Goeman, C. (2003). Water transfers and their impacts: lessons from three Colorado water markets. *Journal of the American Water Resources Association*, 39(5), 1055-1065.

Howitt, R. E. (1994). Empirical Analysis of Water Market Institutions: The 1991 California Water Market. *Resource and Energy Economics*, 16(4), 357-371.

Howitt, R. (1994). Empirical Analysis of Water Market Institutions: The 1991 California Water Market. *Resource and Energy Economics*. 16, 357-371.

Howitt, R.E. (2014). Are lease water markets still emerging in California? in *Water Markets for the 21st Century: What Have We Learned?* K.W. Easter and Q. Huang (Eds.) Vol. 11. Springer-Verlang.

Howitt, R. and Sunding, D. (2011). Water Infrastructure and Water Allocation in California in *California Agriculture: Dimensions and Issues* Jerry Siebert (Ed.) Giannini Foundation available at http://giannini.ucop.edu/CalAgbook.htm

Howitt, R. E., and Lund, J. R. (1999). Measuring the economic impacts of environmental reallocations of water in California. *American journal of agricultural economics*, 81(5), 1268-1272.

Howitt R.E., Medellín-Azuara, J., MacEwan, D., Lund, J., and Sumner, D. (2014) *Economic Analysis of the 2014 Drought for California Agriculture*. Available at https://watershed.ucdavis.edu/files/biblio/Economic_Impact_of_the_2014_California_Water_Drought_1.pdf

Israel, M. and Lund J.R. (1995). Recent California Water Transfers: Implications for Water Management. *Natural Resources Journal*, 35(1), 1-32.

Jenkins, M.W., A.J. Draper, J.R. Lund, R.E. Howitt, S.K. Tanaka, R. Ritzema, and Ward, K..B. (2001). Improving California water management: optimizing value and flexibility. University of California Davis, Statewide Economic-Engineering Water Model—CALVIN.

Jensen, J.R. (2007). *Remote Sensing of the Environment: An Earth Resource Perspective*. 2nd edition, Prentice Hall, NJ.

Khokha, S. As Their Wells Run Dry, California Residents Blame Thirsty Farms. National Public Radio, October 19, 2014 11:42 AM ET Available at: http://www.npr.org/2014/10/19/357273445/as-their-wells-run-dry-california-residents-blame-thirsty-farms Accessed Oct 21st 2014.

Lund, J.R., E. Hanak, W.E. Fleenor, R.E. Howitt, J.F. Mount, and Moyle, P.B. (2008). *Comparing futures for the Sacramento-San Joaquin Delta*. Public Policy Institute of California, San Francisco, CA.

Msangi, S. and R.E. Howitt (2006). Third party effects and aysmmetric externalities in groundwater extraction: the case of Cherokee strip in Butte County, California. prepared paper for the *International Association of Agricultural Economists Conference*, Gold Coast, Australia.

Nuarsa, I.W. and Nishio, F. (2007). Relationships between rice growth parameters and remote sensing data. *International Journal of Remote Sensing and Earth Sciences*, 4, 102-112.

Olmstead, S. (2010). Economics of Managing Scarce Water Resources. *Review of Environmental Economics and Policy*, 4(2), 179–198.

Reisner, M. (1993). *Cadillac Desert: The American West and Its Disappearing Water*. 2nd Edition, Penguin, New York, NY.

Rosegrant, M.W. and Ringler, C. (2000). Impact on food security and rural development of transferring water out of agriculture. *Water Policy*, 1(6), 567-586.

Sauer, J., Davidova, S. and Latruffe, L. (2012). Determinants of Smallholders' Decisions to Leave Land Fallow: The Case of Kosovo. *Journal of Agricultural Economics*, 63: 119–141. doi: 10.1111/j.1477-9552.2011.00321.x

Sperow, M., Eve, M.D., and Paustian. K.H. (2003). Potential soil C sequestration on U.S. agricultural soils. *Climatic Change,* 57(3), 319–39.

Weinberg, M., Kling, C. L., and Wilen, J. E. (1993). Water markets and water quality. *American Journal of Agricultural Economics*, 75(2), 278-291.

Weber, M. L. (2001). Markets for water rights under environmental constraints. *Journal of Environmental Economics and Management*, 42(1), 53-64.

Figure 1: Location of Butte county in Sacramento River Basin in Northern California

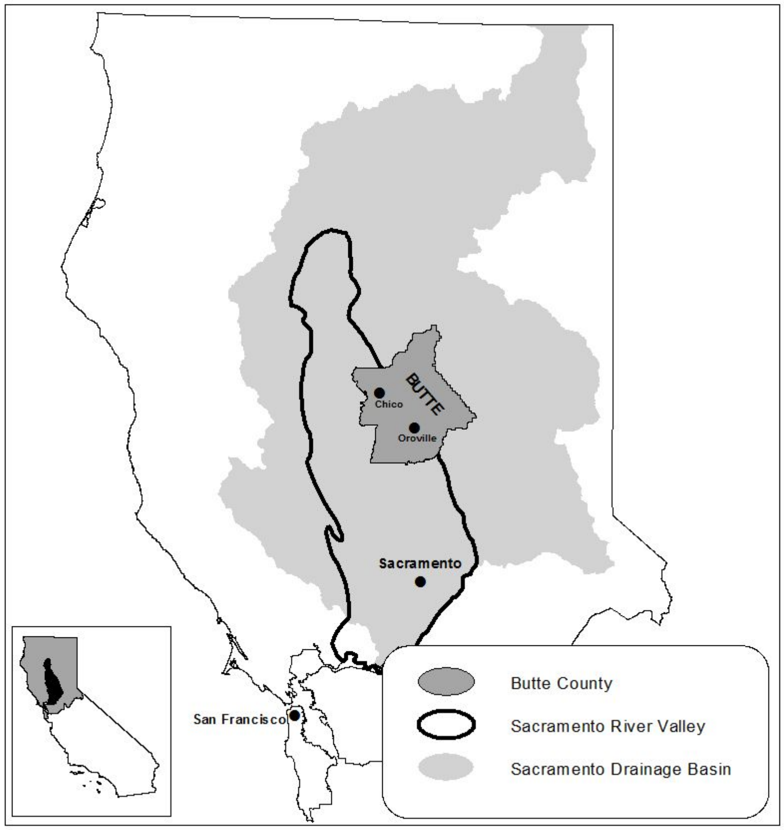


Figure 2: Location of Sample Irrigation Districts and State Water Project Reservoir System in Butte County

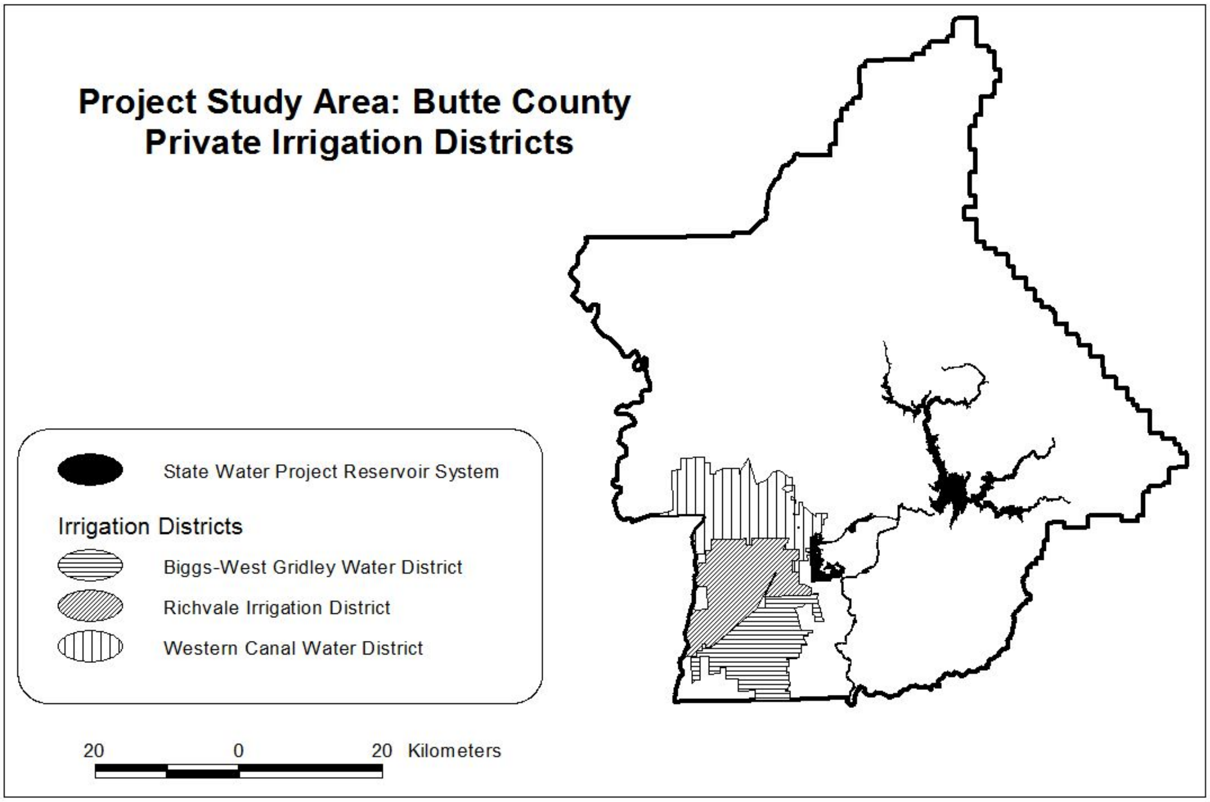


Figure 3: Number of Parcels Fallowed, and Not Fallowed

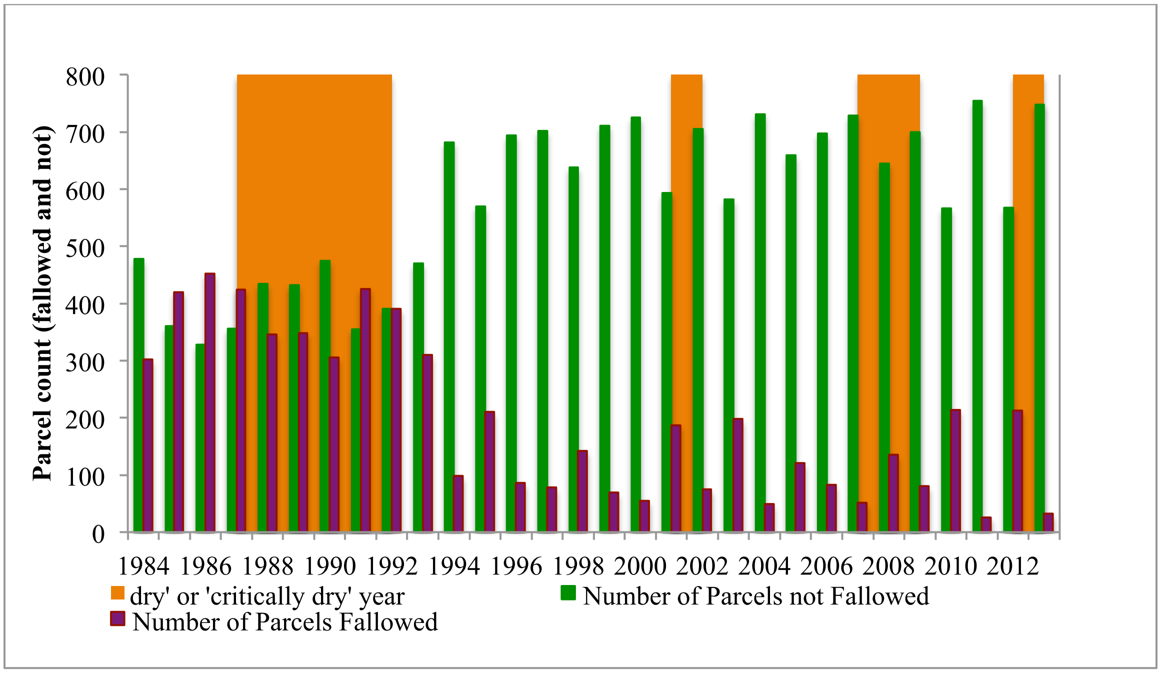


Figure 4: Average Fraction of Parcel by Irrigation District

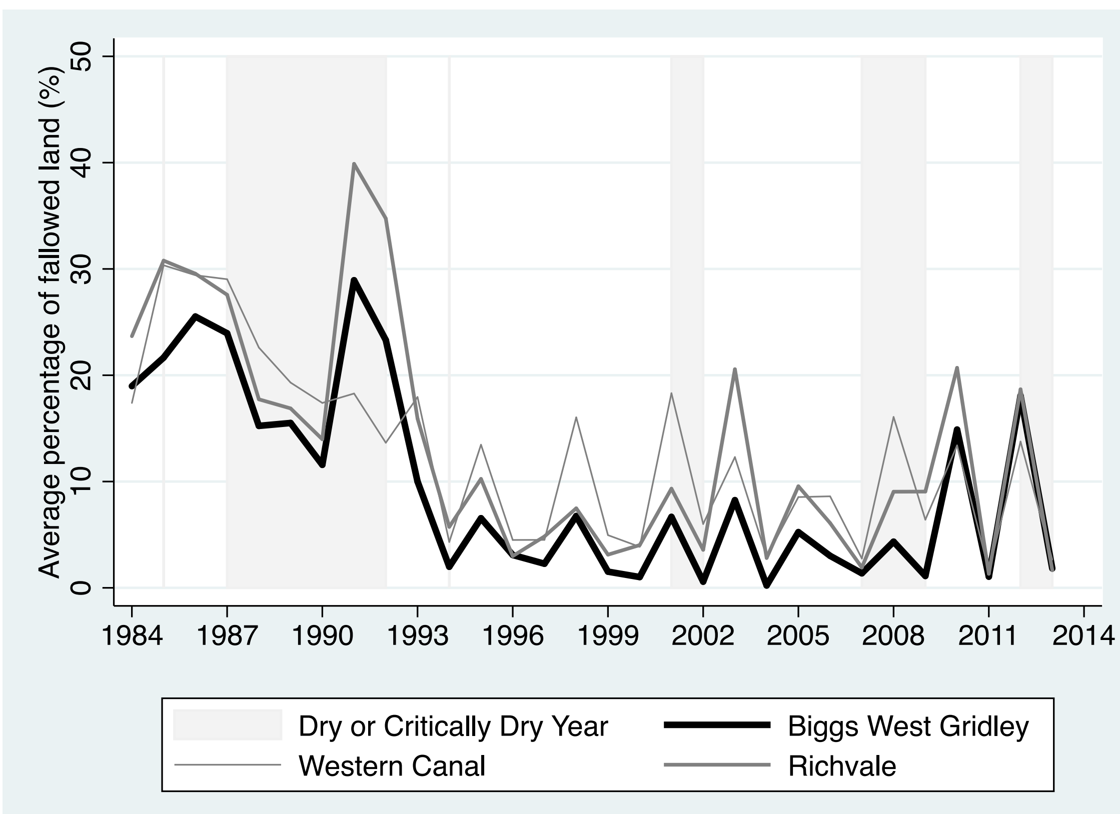


Figure 5: Total Area Fallowed and Price of Rice

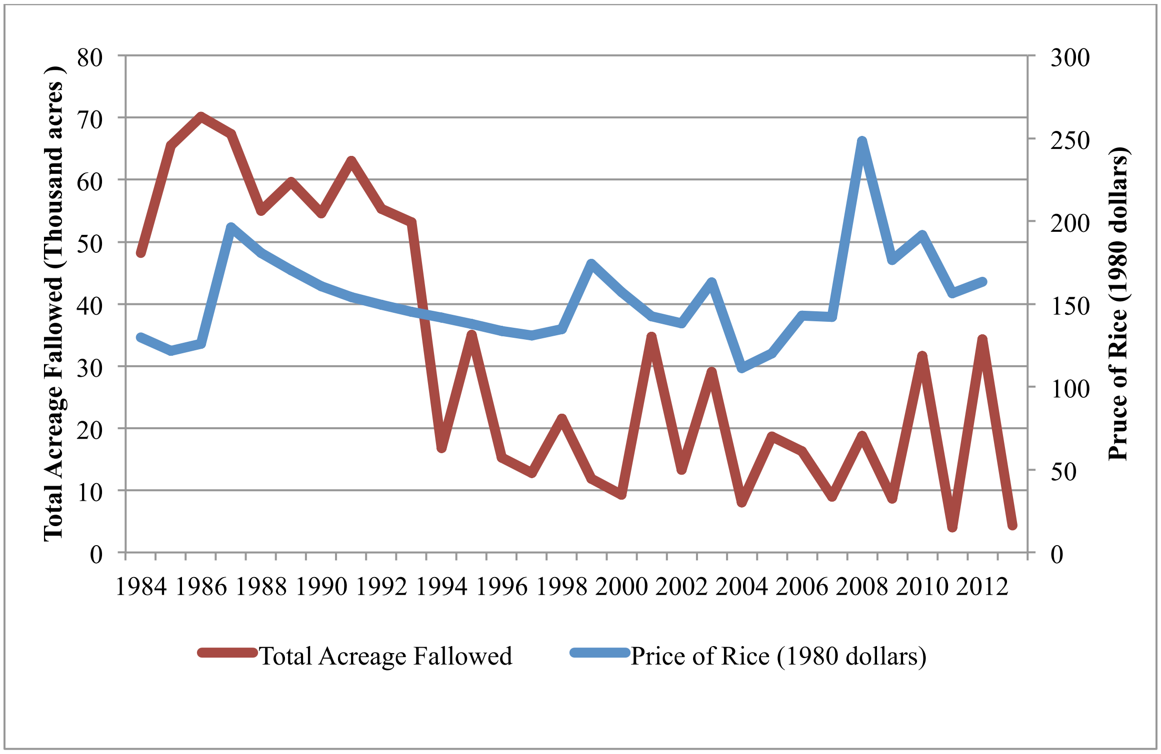


Figure 6: Average fallow fraction ± SD of fallow fraction

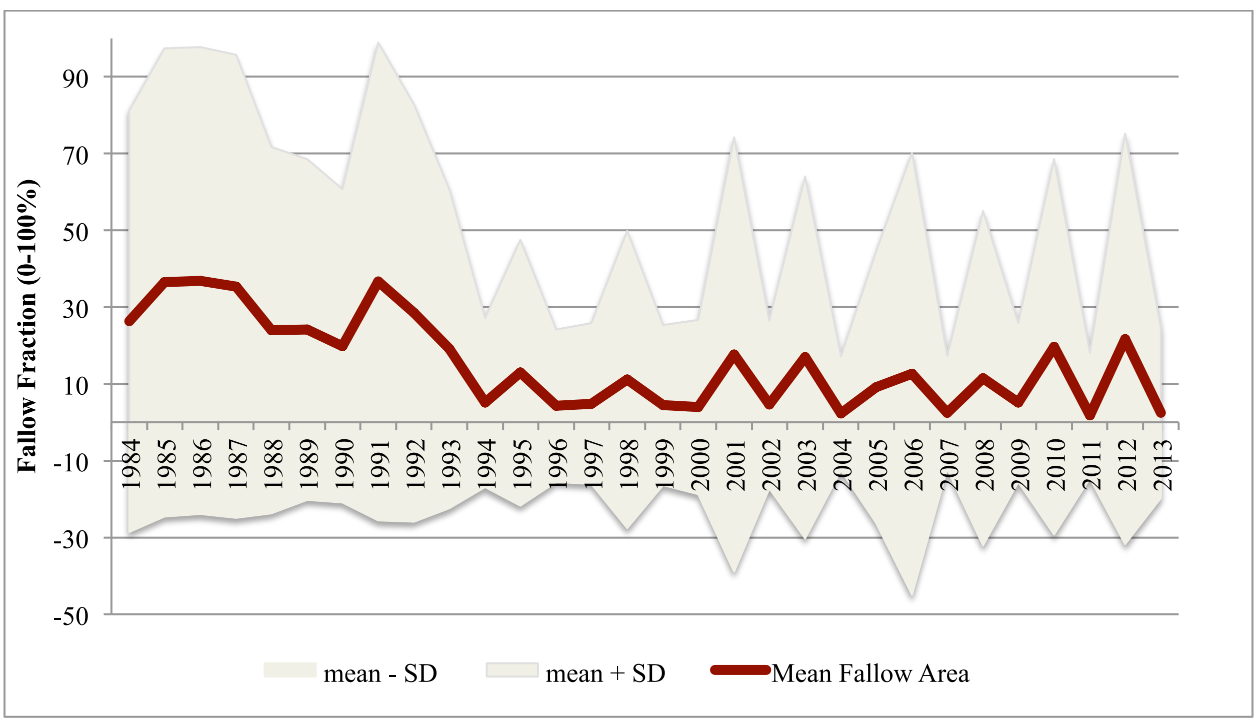
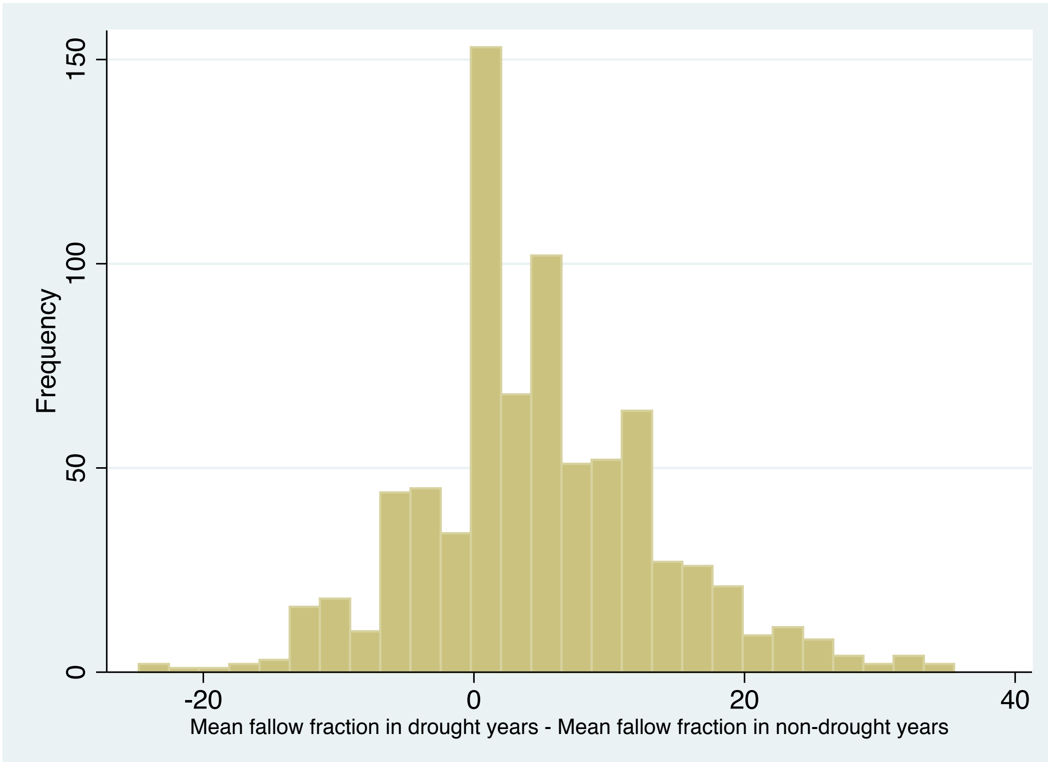
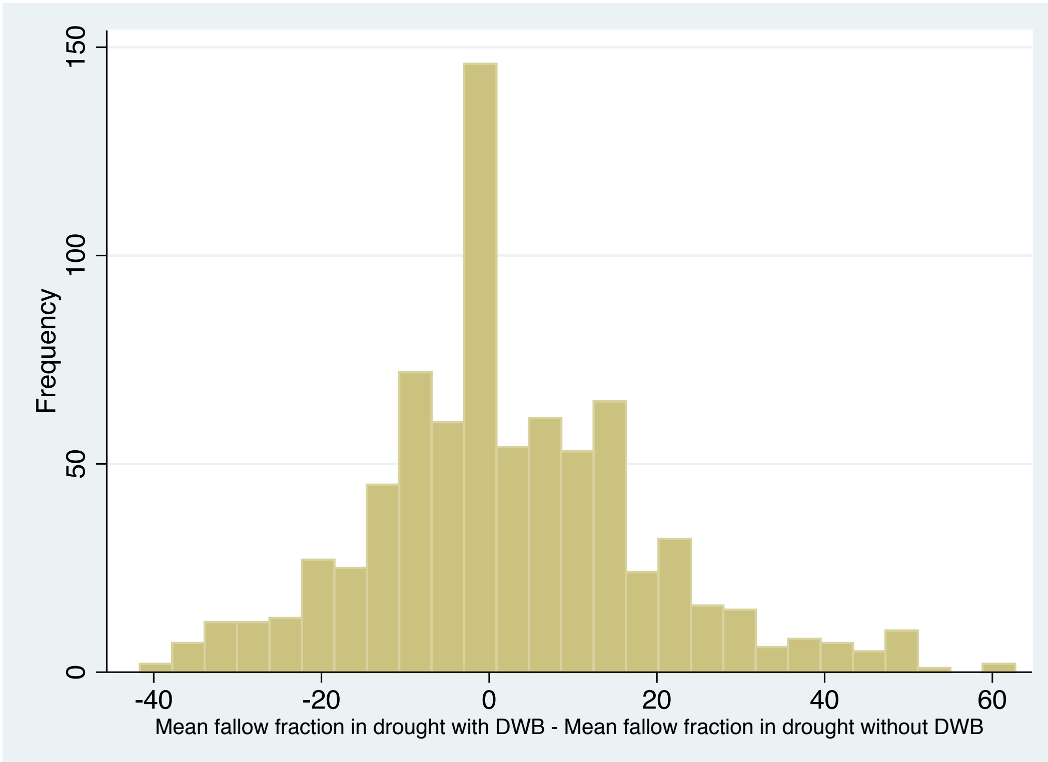


Figure 7: Distribution of Average Difference in Fallow Fraction in Drought and non-Drought years



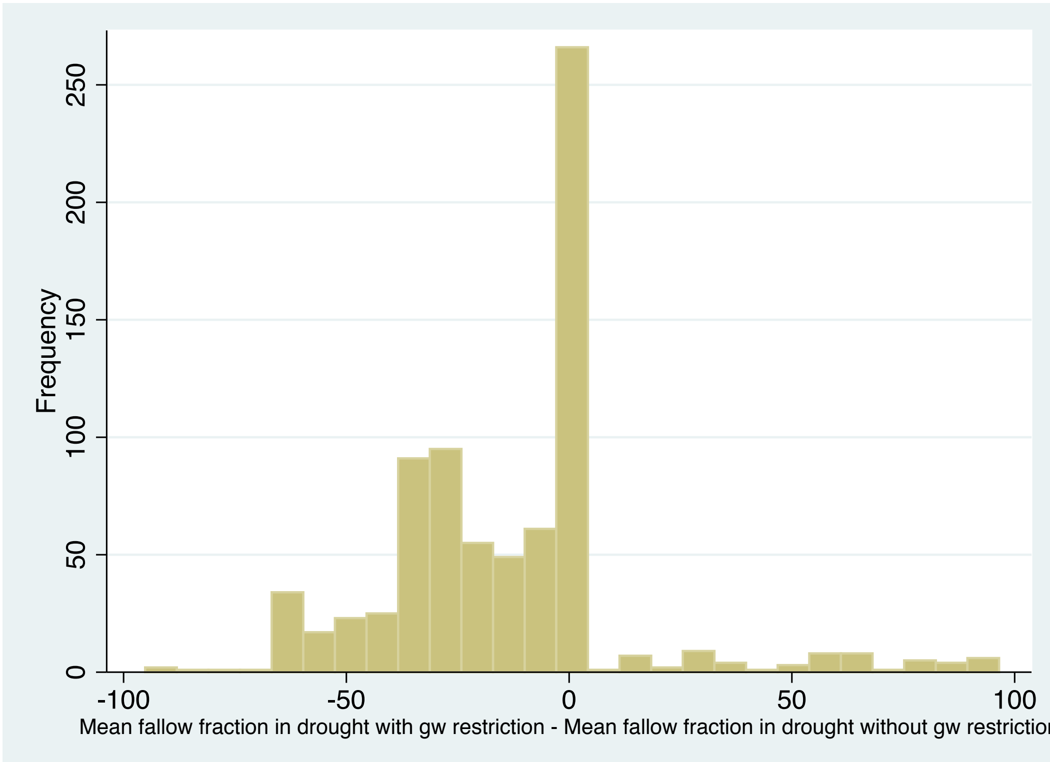
For each parcel in the data, average fallow fraction was computed in dry and critically dry year (drought), $\bar{F}_{i,drought}$ and average fallow fraction was computed for all other years (no drought), $\bar{F}_{i,no\ drought}$. The above figure plots the distribution of the difference between the two averages for all parcels in the data: $\bar{F}_{i,drought} - \bar{F}_{i,no\ drought}$. Parcels to the left of 0 fallow a greater fraction on average in non-drought years (count = 181, average difference = 6 acres), and parcels to the right of 0 are fallowing greater percentage in drought years (count =509, average difference = 9.24 acres). The distribution is skewed slightly to the right, i.e. on more parcels fallow a greater fraction in drought years.

Figure 8: Distribution of Average Difference in Fallow Fraction in DWB and non-DWB years



For each parcel in the data, average fallow fraction was computed in dry and critically dry year with a DWB, $\bar{F}_{i,dry\ with\ DWB}$, and average fallow fraction was computed in dry and critically dry years without DWB, $\bar{F}_{i,dry\ without\ DWB}$. The above figure plots the distribution of the difference between the two averages for each parcel: $\bar{F}_{i,dry\ with\ DWB} - \bar{F}_{i,dry\ without\ DWB}$. Parcels to the left of 0 fallow a greater percentage in non-DWB years (count = 181, average difference = 2.24 acres), and parcels to the right of 0 are fallowing greater percentage in DWB years (count =509, average difference = 2.67 acres). The distribution is very slightly skewed to the right, i.e. on average more parcels fallow a lightly greater fraction in DWB years than they do in drought years without a DWB.

Figure 9: Distribution of Average Difference in Fallow Fraction after Groundwater Restriction in 1996



For each parcel in the data, average fallow fraction was computed in or before 1996 for DWB years $\bar{F}_{i,pre\ 96}$, and average fallow fraction was computed post 1996 for DWB years, $\bar{F}_{i,post\ 1996}$. The above figure plots the distribution of $\bar{F}_{i,post\ 1996} - \bar{F}_{i,pre\ 96}$. Parcels to the left of 0 fallowed greater fraction before measure G (count = 492, average difference = 28 acres), and those to the right of 0 fallowed a smaller fraction after measure G (count = 64 average difference = 49 acres). Although smaller number of parlces lie to the right, their average difference in fallow fraction is greater: 49 acres, compared to 28 acres.

Table 1: Summary of Drought Water Banks Table 3: Summary Statistics

Year	1991	1992	1994	2009
Announcement Date	February 15th, 1991 Contracts were signed between February and April [a]	March 10th, 1992 [c]	June, 1994 [d]	September 4th, 2008 [e]
Total Volume Purchased	820,655 acre feet [b]	193,193 acre feet [d]	220,000 acre feet [d]	75,000 acre feet [f]
Total Volume Sold	389,970 acre-feet [b]	158,715 acre feet [d]	170,000 acre feet [d]	
Purchase Price	\$125/acre-feet [b]	\$50/acre feet [d]	\$50/acre feet [d]	\$275/acre feet [f]
Sale Price	\$175/acre-feet [b]	\$72/acre feet [d]	\$68/acre feet [d]	\$275/acre feet + conveyance costs + administrative costs [f]
Rice Specific Details	• 4.9% of fallowed crops were rice • 8,180 acres of rice were put in the DWB through non-irrigation contracts • On average, 3.5 AF/acre of rice were sold to the DWB, through the NI contracts [b]	Water Bank did not purchase water conserved through the fallowing of agricultural lands [d]	Water Bank did not purchase water conserved through the fallowing of agricultural lands [d]	• Price of rice was relatively high in the Sacramento Valley, which made sales to the water bank less economically attractive • Buyers would lose 40% of the estimated water from rice growers [f]
Source Contracts	• 52% (325 contracts) Non-Irrigation • 32% (19 contracts) Ground Water Substitution • 18% (4 contracts) Surface Water [b]	• 11 contracts • 86% Ground water substitution contracts • 14% Surface Water Contracts [d]	• 85% Groundwater Substitution Contracts • 15% Surface Water Contracts [d]	
Destination Allocation	• 12 urban entities purchased water. • Metropolitan Water District of Southern California purchased 55% [b]	• 60% - Agricultural Uses • 15.4% Fish and Wildlife Demands • 24.6% Urban Uses [d]	• 85% - Agricultural Uses • 15% Urban Uses [d]	

[a] RAND (1993) “California’s 1991 Drought Water Bank: Economic Impacts in the Selling Regions” Dixon, L.S., Moore N.Y. & Schechter S.W.
[b] Department of Water Resources, State of California, (1992, January), “The 1991 Drought Water Bank”
[c] Malchow D. (May 1992), “A Review of California Water Transfers”, Environs, Vol. 16, Number 1, p.51-59
[d] Department of Ecology, State of Washington & WestWater Research (2004) “Analysis of Water Banks in the Western States”, Clifford P., Landry C. & Larsen-Hayden A.
[e] Plitz, R. (2008, September 7) “California creates a “water bank” to handle chronic drought: Will it be temporary, or permanent? ”, Climate Science Watch
[e] Department of Water Resources, State of California, “2007-2009 Drought Timeline”
[f] Department of Water Resources, State of California, (2010, September) “California’s Drought of 2007-2009; An Overview”

Notes:

*Non-irrigation Contracts - The farmers were paid to not irrigate a certain portion or all of their fields

*Groundwater Contracts - Groundwater pumped directly from the ground was paid for by the DWR. In this case, the sellers were required to reduce surface water consumption by the amount of ground water pumped.

Table 2: Parcel Description by Irrigation District

Irrigation District (ID)	Mean parcel size$^{\varsigma}$ (acres)	Std. Dev. of parcel size$^{\varsigma}$	Mean fallow fraction$^{\varsigma}$	Number of parcels	Total area in all parcels (acres)
Western Canal ID	160.41	147.96	12.68	256	41065.29
Richvale ID	101.83	105.33	13.45	313	31872.13
Biggs-West Gridley ID	114.74	124.55	9.48	211	24209.44

Notes: $^{\varsigma}$ Computed within ID

Table 3: Mean Fallow Fraction

Variable	Mean	Std. Dev.	Min	Max
Mean fallow fraction in wet years	9.80	7.93	0.00	49.82
Mean fallow fraction in dry or critically dry years	14.44	9.87	0.00	51.64
Mean fallow fraction in dry or critically dry years without DWB	11.49	7.81	0.00	46.53
Mean fallow fraction in dry or critically dry years with DWB	16.21	16.16	0.00	71.37

Table 4: Explaining Fallowing Decisions (Fixed effects model)

Dependent variable: Fraction of fallowed land (0-100 percent)

Explanatory variables	(1)	(2)	(3)	(4)	(5)
Year	-0.668***	-0.652***	-0.619***	-0.586***	-1.117***
	(0.0191)	(0.0191)	(0.0211)	(0.0214)	(0.0533)
Dry or Critically dry year		3.818***	3.865***	4.061***	3.584***
		(0.331)	(0.372)	(0.371)	(0.373)
Real Price of Rice (t-1)			-2.440***	-3.703***	-10.36***
			(0.688)	(0.825)	(0.920)
Drought Water Bank 1991				11.92***	
				(0.941)	
Drought Water Bank 1992				7.154***	
				(0.935)	
Drought Water Bank 1994				-12.47***	
				(0.933)	
Drought Water Bank 2009				1.921	
				(1.202)	
All Drought Water Banks in 1991 1992 1994 2009			1.790***		2.948***
			(0.548)		(0.627)
Groundwater Restriction Dummy					2.351***
					(0.780)
Contiguous Fallow Restriction Dummy					2.819**
					(1.351)
Fallow Acreage Restriction Dummy					12.55***
					(1.475)
Constant	22.47***	20.31***	23.24***	24.49***	39.39***
	(0.340)	(0.387)	(0.977)	(1.216)	(1.461)
Observations	23,400	23,400	22,620	22,620	22,620
R-squared	0.051	0.057	0.057	0.075	0.075
Number of parcels	780	780	780	780	780

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 5: Explaining Fallowing Decisions (Fixed effects logit model)

Dependent variable: Fallow status = 1 if any fraction is fallowed, = 0 if not fallowed.

Explanatory variables	(1)	(2)	(3)	(4)	(5)
Year	-0.105***	-0.101***	-0.105***	-0.101***	-0.129***
	(0.00224)	(0.00222)	(0.00246)	(0.00251)	(0.00601)
Dry or Critically dry year		0.465***	0.425***	0.459***	0.353***
		(0.0352)	(0.0421)	(0.0425)	(0.0430)
Real price of rice (t-1)			-0.0935	-0.211**	-0.613***
			(0.0778)	(0.0923)	(0.0972)
Drought Water Bank 1991				0.724***	
				(0.0866)	
Drought Water Bank 1992				0.584***	
				(0.0854)	
Drought Water Bank 1994				-1.559***	
				(0.121)	
Drought Water Bank 2009				-0.0858	
				(0.158)	
All Drought Water Banks in 1991 1992 1994 2009			0.0306		0.0758
			(0.0524)		(0.0601)
Groundwater Restriction Dummy					-0.204**
					(0.0841)
Contiguous Fallow Restriction Dummy					0.653***
					(0.169)
Fallow Acreage Restriction Dummy					0.890***
					(0.176)
Observations	21,420	21,420	20,619	20,619	20,619
Number of parcels	714	714	711	711	711

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Results of logit model, not marginal effects; for marginal effects, see Table 6

Table 6: Marginal Effects of Logit Model

Dependent variable: Dummy variable indicating fallowed (=1), not fallowed (=0)

Explanatory variables[ς]	(1)	(2)	(3)	(4)	(5)
Year[Δ]	-0.014	-0.017	-0.015	-0.013	-0.008
Dry or Critically dry year[Δ]		0.077	0.059	0.059	0.021
Real price of rice (t-1)			-0.013	-0.027	-0.037
Drought Water Bank 1991[Δ]				0.116	
Drought Water Bank 1992[Δ]				0.090	
Drought Water Bank 1994[Δ]				-0.121	
Drought Water Bank 2009[Δ]				-0.011	
All Drought Water Banks in 1991 1992 1994 2009[Δ]			0.004		0.005
Measure G passing 1996[Δ]					-0.012
Max acre 320 for snake[Δ]					0.049
Max fraction fallowed < 20 percent [Δ]					0.070

[ς]Marginal effects computed at mean of independent variable

[Δ]dy/dx is for discrete change of dummy variable from 0 to 1

Table 7: Results of Equation (2) for Fallow Fraction and Fallow Status

	(1) Dependent variable: fallow fraction= 0-100 percent	(2) Dependent variable: Fallow status = 1 if any fraction is fallowed, = 0 if not fallowed.
Year	-1.117***	-0.130***
	(0.0532)	(0.00604)
Dry or Critically dry year	3.584***	0.357***
	(0.372)	(0.0431)
Real price of rice (t-1)	-10.36***	-0.619***
	(0.917)	(0.0976)
All Drought Water Banks in 1991 1992 1994 2009	8.896***	0.546***
	(0.936)	(0.0916)
Groundwater Restriction Dummy	2.351***	-0.206**
	(0.778)	(0.0845)
Contiguous Fallow Restriction Dummy	2.819**	0.613***
	(1.347)	(0.169)
Fallow Acreage Restriction Dummy	12.55***	0.942***
	(1.470)	(0.176)
DWB x BWG ID	-5.277***	-0.171
	(1.184)	(0.123)
DWB x WC ID	-12.73***	-0.801***
	(1.141)	(0.114)
DWB x Area	-0.00274	-0.00116***
	(0.00378)	(0.000373)
Constant	39.39***	
	(1.457)	
Observations	22,620	20,619
R-squared	0.081	
Number of parcels	780	711

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1