Climate Change, Water Supply, and Agriculture in the Arid Western United States: Ninety Years of Agricultural Census Observations from Idaho

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January 2016

Preliminary and Incomplete Draft
Please do not cite

Abstract:
This paper addresses the long-term impacts of climate change and water supply conditions on agricultural decisions in the arid western United States. We account for the main outcomes of climate change, such as the inter-annual volatility of total water supply and the in-season distribution of stream flow observations, and estimate the impacts that climate change and other water supply factors have on county-level agricultural activities, such as total acreage, harvested acres, and farmland value, all measured over the past 90 years in Idaho. In our models, we control for the time-varying development of water rights that govern water use and allocation, and explain the impact of water rights institutions in the arid west.

I. Introduction and Brief Background

Most of the previous studies of the impacts of climate change on agriculture have focused on localized, intra-season precipitation and temperature effects (Adams 1989; Adams et al. 1990; Mendelsohn et al. 1994; Adams et al. 1995 and 1999; Deschênes and Greenstone 2007; however, Schlenker et al. 2005 is an exception to this). Although this is relevant for the more humid East, these measures are less useful for agricultural production in the arid West. Specifically, irrigators in the snowmelt-dominated basins in the arid West are more dependent on pre-season snowpack, as 50%-80% of the total irrigation water in the North American West results from snowmelt - driven runoff in spring, which feeds irrigation throughout the growing season (Stewart et al. 2004). The water sources utilized for irrigation by farms in the arid West flow from snowpack-dominated storage hundreds or thousands of miles from the farms themselves, and are subject to spatially-differentiated water rights hierarchies that were established decades before the agricultural decisions were made.

In this paper we address how volatilities in inter-annual water supply and historical water rights impact agricultural outcomes in the arid West. In most of the West, these changes include trends toward earlier snowmelt-driven streamflows (Cayan et al. 2001; Stewart et al. 2005) that are more pronounced at lower elevations (Regonda et al. 2005), reduced late-season flow and increased early-season flow (Stewart et al. 2005). The most significant impact of a general warming was found to be a large reduction in mountain snow pack and a substantial shift in streamflow seasonality, so that by 2050, the spring streamflow maximum is expected to arrive one month earlier in the year (Barnett et al. 2005). Since climate change reflects a long-term trend and adaptation and mitigation efforts take time to show their effects, it is necessary to investigate such impacts of climate change and water supply over a longer time span. Thus, utilizing historical agricultural data will provide insight on what some of the future outcomes may be.

In Idaho, like many agricultural areas in the arid west, measures of precipitation occurring prior to the growing season are second-best approximations of total water availability when compared to measures of snowpack or actual streamflow during the growing season. Yet snowpack is not a good measure of water supply. Studies have suggested that automated, fixed point, in situ snow measurements, which are the norm at many observation sites and are used for hydroclimatological analyses and decision making, consistently over- or under-represent the actual snow depth (Neumann et al., 2006). In addition, in many cases the snowpack occurs at great distances from the farms that will eventually utilize the irrigation water resources, and thus care has to be taken in matching the farm with the hydrologic basin which will eventually provide the water resources.

A number of institutional factors further complicate this analysis, most notably the priority of water rights in respective water types (e.g.: surface, ground, etc.). Water rights priority systems were established to assign a hierarchy of access to the water resources, and to prevent or resolve conflicts. Because of the increased access to water, by the turn of the century much of the yearly flow in any given river had been allocated. The continued distribution of (junior) water rights resulted in a condition in which a significant portion of the irrigated acreage may be curtailed at much earlier stage of each growing season, particularly during a severe water shortage. This may result in some irrigators transitioning to more drought-tolerant crops or alternative cropping practices, which in turn could alter the crop diversity and agricultural landscape if such conditions persist.

A similar advancement, with regards to accessing water, evolved with the electrification of the farm: Electrification enabled lands that consistently lacked surface water access and lands that regularly lacked surface water allocations (not because of access, but because of the institutional priority "vintage" constraints – junior water rights holders,) to now have access to water. It isn't cheap – pumping is expensive, and is a backstop for surface water use – but it is more reliable and consistent, particularly for the junior irrigators that are more likely to be curtailed in any given year. Anecdotal evidence points to this irrigation method being preferred by some growers, because it enables them to sign contracts (guarantees) to grow crops that might otherwise be more risky if they have to rely on surface water sources, and the potential of being curtailed.

In order to address these complexities, we integrate county-level agricultural census data with water rights data and water supply indices. Because of the heterogeneity of surface and groundwater resources across the state, as well as their availabilities over time, we disentangle both the composition of water sources for each county and the priority hierarchy for those counties. In this case we could observe a groundwater dominated county (with generally junior water rights,) that behaves much like a surface-water dominated county (with generally senior water rights). For our water availability measure, we use measures of the total water available during the growing season, as well as the long-term observed streamflow measures for the main water source for each county. Because curtailment usually happens later in the growing season, and because the timing of the onset and distribution of snowmelt-driven streamflow are predicted to shift to earlier in the growing season, we also calculate a measure of the total water available in August-September vs. the entire growing season (April-September). These measures account for the growth of major water infrastructure and storage, which impacts the streamflow measures that we utilize.

We use the water rights and water supply data together with agricultural census measures of farmland values, total acreage, and harvested acreage in order to address the long-run impacts of water supply availability on agricultural outcomes in Idaho. Specifically, we anticipate that the increase in inter-annual water supply volatility—due to the reduction in mountain snow pack and a substantial shift in streamflow seasonality from late-season to earlier snowmelt-driven streamflows, impacts agricultural outcomes, reducing successful harvest acres, increasing crop failures and eventually reducing the farmland values. Thus, we hypothesize that the *increase* in inter-annual water supply volatility will lead to a *decrease* in total cropland acres, in harvested acres (e.g. increase in crop failures), and in farmland values. Moreover, we expect that the water rights distribution—including seniority of water rights, types of rights (ground vs. surface), and variation of water rights distribution, will mitigate or contribute to the impact of the increase in inter-annual water supply volatility on these agricultural outcomes and farmland values.

Our preliminary results show that an increased availability of annual streamflow during the later part of the growing season (Aug – Sept) results in more cropland, in increased harvested acres (e.g. in lower crop failures) and in some cases in higher farmland values. Water supply volatility on the other hand, measured by coefficient of variation in annual streamflow, lowers cropland and harvested acres. In addition, we find that (not surprisingly), the more the surface and / or ground water rights acres a county has, the more cropland and successfully harvested acres as well as higher farmland values the county has over time. Specifically, a higher ratio of surface and ground water rights acres in a county results in more cropland and harvested acres, and higher farmland values. The significance of ground-to-surface water rights acreage ratio in many of our models indicates the importance of having access to consistent and reliable water, through access to ground water, on agricultural outcomes and average farmland values. Moreover, the variation in the vintage of these water rights matter as well: counties that have access to both surface (generally more senior) and ground (generally more junior) water rights have more cropland acres, harvested acres, and higher farm land values.

II. Data Description and Descriptive Statistics

In order to analyze the impact of weather variability and water rights institutions on agricultural activities, we have compiled the most detailed data available on historical water supply, weather phenomena, agricultural activities and other relevant data, including the geographic and water rights characteristics of our study area. Within the 44 counties in Idaho there is tremendous variation in annual temperature trends, precipitation, and the availability of irrigation water. As Idaho is located to the east of the rain shadows of the Sierra Nevada, Cascade and Coastal Ranges, some counties receive less than ten inches of precipitation annually. Other counties, like those that reside at the foothills of the Rocky Mountains which span the eastern border and panhandle of the state, receive three times as much precipitation as their more western counterparts. Surprisingly, much of the prime agricultural land in Idaho falls in the arid Snake River Plain of the Great Basin, receiving a fraction of the annual precipitation that other parts of the state receive. These arid counties all require additional irrigation in order to grow crops in a water-intensive fashion.

The following sections describe our data sources, discuss the mechanisms that were used to assign non-uniform counts and averages to the counties, and present summary statistics on trends in major water supply, agriculture, and weather characteristics.

Census of Agriculture Data

Historical agriculture data from the U.S. Census of Agriculture have been collected and inputted manually from hard-copy historical agricultural census records. The data include 19 observations for each county in the sample, assembled between 1920 and 2007. After 1920 the Agricultural Census was conducted every 5 years, with slight variations in 1954, 1978 and 1982.[1] From the agricultural census data several different measures of agricultural coverage are used, including: total cropland, total cropland harvested, and average value per acre.[2]

The starting point for our analysis (Agricultural Census year 1920) was chosen for a number of reasons, the most important of which were consistency in geographic boundaries, the availability of census data, and the ability to match other data in our analysis. Unlike the previous studies (for example, Hansen et al. 2014; and Hansen et al. 2011) that utilize historical agricultural census data and had to account for spatial and data inconsistencies over time, the county boundaries in Idaho remained almost entirely spatially uniform from 1920 to present. Similarly, because we rely on cropland area and revenue measures for our dependent variables which haven't changed over time, the units of measurement for our dependent variables are consistent across all of the years of our sample.[3] Table 1 provides the descriptive statistics for all measures used in our analyses and shows brief explanations for each constructed variable.

[1] Our yearly observations include 1920, 1925, 1930, 1935, 1940, 1945, 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997, 2002, and 2007.

[2] The value per acre measure is presented by the U.S. Census in nominal terms. We use the Consumer Price Index measures provided by the Bureau of Labor Statistics to normalize the values into real terms (1984$)

[3] The total cropland, total cropland harvested and average revenue per acre variables were included in the official U.S. Agricultural Census for all of the years in our sample, therefore they should be available for all 836 observations (44 counties x 19 census years) in our sample. In a small handful of cases count data was purposefully omitted from the agricultural census – most notably when the number of farming operations in the county was small enough so as to make anonymity of data impossible. Because of this, from model to model there may be small variations in the total number of observations available.

Weather and Climate Data

The U.S. Climate Division Dataset (USCDD) provides averaged weather and climate data based on 344 climatic zones, covering 1895 to present.[4] The USCDD includes various temperature and precipitation measures, such as the monthly max, min, mean temperatures, and total monthly precipitation.[5] In our empirical models we use the USCDD data to construct four independent variables for the growing season within which the Agricultural Census data was collected: the total seasonal precipitation (in inches); the average monthly temperature (in Fahrenheit), and lagged seasonal measures of each of the previous two measures.[6]

The USCDD is zonal in nature: dividing each state into similar climate zones. Unlike monitor-level temperature and precipitation data, the zonal climate data utilize all of the monitor readings within a zone to arrive at zone-averaged temperature and precipitation measures. For our purposes, the zonal nature of the USCDD matches well with the Agricultural Census data, and guarantees that weather data is available for every county, for every year in our sample. Unfortunately, the zones reflect topographic and meteorological uniformities, and therefore don't conform to sociopolitical county boundaries. For this reason, in order to assign zonal climate and weather data to counties that overlap multiple zones, the zonal data must be averaged across the overlapping counties.[7]

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[4] Our sample includes 10 distinct climate zones in Idaho.

[5] The Climatic data are from the Area Resource File (ARF). The ARF file is maintained by Quality Resource Systems (QRS) under contract to the Office of Research and Planning, Bureau of Health Professions, within the Health Resources and Services Administration.

[6] In the robustness checks, we also include indices and lagged indices of drought. These indices include the long-term Palmer Drought Index (PDSI), and the short-term Palmer "Z" Index (ZNDX). However, because these indices tend to be zonal in nature, and we include basin-level fixed effects in our models, it isn't surprising that their effects aren't significant.

[7] We use an evenly weighted average – so if a county falls in two zones, the temperature and precipitation values that are assigned that that county would be 50% of the first zone and 50% of the second zone. As an example, of the 44 counties in Idaho, 28 are contained in a single climate zone, 9 overlap with 2 climate zones, 5 overlap with 3 climate

Water Supply Data

The water supply data are compiled by U.S. Department of Agriculture, Natural Resource Conservation Services (NRCS) (last retrieved, September 2015). Per the NRCS, the Historic Monthly Adjusted Stremflow totals are the total water available (in thousands of acre feet,) “adjusted by adding upstream reservoir change-in-storage volumes and major diversions to the observed monthly streamflow volumes to reflect a ‘natural flow’ condition” (NRCS 2015). The raw streamflow data is presented as a monthly total, and is measured at NRCS streamflow forecast points across the state.

Streamflow forecast points are selected so as to reflect the streamflow volume of the major river that provides water to the county. Although most counties in Idaho receive their water from a point along one of the major river sources (for example, the Snake, Salmon, Payette, Big Wood, Portneuf, and Boise rivers,) some counties receive surface water deliveries from multiple major rivers. In our models the streamflow measure is not intended to present the aggregate volume of water available, but rather to reflect the availability of surface water, relative to a long term norm – and enters our empirical analysis as a percentage value.

This raw streamflow data is used to construct a number of surface water independent variables, including: 1) the ratio of the total seasonal water supply to the long term average total seasonal water supply (October of the prior year through September of the Agricultural Census year,); 2) the percentage of the seasonal water supply delivered during the (often water-short) summer months relative to the total seasonal water supply (i.e.: July, August and September vs. the October-September irrigation season); and 3) a coefficient of variation for surface water supply

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zones, 1 overlaps with 4 climate zones, and 1 overlaps with 5 climate zones. As a robustness check, we run models with only those counties that are contained in a single climate zone.

(the standard deviation of monthly seasonal surface water supply divided by the mean monthly surface water volume within the season).

Water Rights Data

The water rights geospatial data are compiled by the IDWR (last retrieved, July 2014), and include 57,081 individual irrigation water rights for the state of Idaho. We use the *Place-of-Use* data layer, which contains the essential aspects of a water right, including the priority date, place of use, and total acreage. We divide the water rights data into two categories -- surface water rights and groundwater rights -- and we use this data to construct a number of county-specific, year-specific water right variables, including the total number of water rights, the total acreage of water rights, and the mean priority date. For each county we calculate the standard deviation of the priority date for all water rights that are present in that census year, and we calculate the number of water rights that fall within one standard deviation of the average priority date for each census year.

We use these measures to construct five independent variables that address water rights: 1) the percentage of the total county area covered by groundwater rights; 2) the percentage of the total county area covered by surface water rights; 3) the ratio of groundwater right area to surface water right area; 4) a coefficient of variation for surface water right priority dates (the standard deviation of surface water right priority date divided by the mean surface water priority date); and 5) a coefficient of variation for the total number of surface water rights (the number of surface water rights that fall within one standard deviation of the mean divided by the total number of surface water rights).[8]

[8] In our robustness checks we also test for the influence of the mean surface and groundwater rights priority dates for each observation in our sample, as well as for non-linearities in the priority dates.

III. Conceptual Framework and Empirical Model

Historically, Idaho has been an agriculture-dominated state with a vast agricultural demand for water,[9] and the agricultural production is critically dependent on water. Thus, the main consequences of climate change such as inter-annual volatility of total water supply and the in-season distribution of stream flow observations are expected to be especially impactful on agriculture in Idaho, an arid and semi-arid region. Irrigators in the snowmelt-dominated basins in the arid West are especially dependent on pre-season snowpack, and a significant impact of a general warming is a large reduction in mountain snow pack and a substantial shift in streamflow seasonality from late-season to earlier snowmelt-driven streamflows. Thus, we expect this increase in inter-annual water supply volatility to impact agricultural outcomes, reducing successful harvest acres, increasing crop failures and eventually reducing the farmland values[10]. Since climate change reflects a long-term trend and adaptation and mitigation efforts take time to show their effects, and the impact of volatility in climate has been observed historically, we utilize historical agricultural data will to investigate such impacts of climate change and water supply over a longer time span and understand possible future agricultural outcomes as the impact of climate change intensifies.

Thus, we consider a simple conceptual framework where we posit that the productivity of agriculture (H) is a function of water supply-related factors (W) and other factors that have an impact on agricultural production (X). That is:

$$H_{it} = H(W_{it}, X_{it}) \tag{1}$$

[9] According to the water-use statistics available to the public, irrigation in Idaho accounts for 92.4%, 86.1%, 87.7%, and 85.1% of the total water withdrawals in the survey years of 1985, 1995, 2000, and 2005 respectively (USGS, 1988; 1998; 2004; 2009).

[10] The increase in inter-annual water supply volatility likely impact the crop mixes as well, although the impact on crop mixes is not examined in the current paper.

The water supply related factors include the seasonal streamflow data, and various water right priority measures as well as the ratio of agricultural area dedicated to surface and groundwater water rights. Other factors affecting agricultural production include long-term climate conditions such as the annual precipitation and temperature. Under this basic conceptual framework, we hypothesize that *ceteris paribus*: increase in inter-annual water supply volatility in the relevant county will lead to a decrease in 1) total agricultural acres, 2) harvested acres (e.g. increase in crop failures), and 3) farmland values. Moreover, the water rights distribution—including seniority of rights, types of rights (ground vs. surface), and variation of water rights distribution in a relevant county will mitigate or contribute to the impact of the increase in inter-annual water supply volatility on these agricultural results and farmland values.

Empirical Model

To evaluate the impact of water supply, weather variability and water rights institutions on agricultural activities, we specify and estimate fixed effects OLS models using the data sources outlined in the previous section. We let C_{it} denote the agricultural outcome in county *i*, in year *t*, and we allow C_{it} to represent: 1) the total county area in cropland; 2) the percentage of cropland that is harvested; and 3) the real farmland value per acre.[11]

In order to account for spatial and temporal unobservable factors, we introduce both year fixed effects and basin fixed effects. We cluster counties based on their hydrologic basin, and therefore identification comes from the within-cluster differences in the covariates over time. In the case of Idaho, counties within clusters are very similar in agricultural potential (soil type,

[11] It is worth noting that because counties are not uniform in size, (1) and (2) may be biased by the size of the county. We therefore normalize these values by the total land area of the county.

topography, annual precipitation totals, annual temperature averages) and they share a major surface water source.[12] Identification therefore comes from the within-cluster differences in the seasonal water supply availability and the changes in water rights distributions over time.

Our basic econometric model is equation (2) below:

$$C_{it} = \mathrm{X}^1_{it}\alpha + \mathrm{X}^2_{it}\beta + \mathrm{X}^3_{it}\gamma + \theta_t + \delta_g + \eta_{it} \tag{2}$$

where $\mathrm{X}^1{}_{\mathrm{it}}$ is a vector of water supply controls that vary over time at the county level, and includes the total seasonal water supply as a percentage of the long-run average, the late season water supply as a percentage of the total season water supply, and a coefficient of variation for the within-season monthly water supply**.** $\mathrm{X}^2{}_{\mathrm{it}}$ is a vector of water right controls that vary over time at the county level, and includes percentage of the county (area) that has surface water rights, the percentage of the county (area) that has groundwater rights, the ratio of ground water rights to surface water rights, and a coefficient of variation for surface water rights within the county. $\mathrm{X}^3{}_{\mathrm{it}}$ is a vector of weather controls that vary over time at the county level, and includes the total precipitation and average monthly temperature, all measured during the growing season. θ_t is a year fixed effect, δ_j is a cluster (basin) fixed effect for counties with similar topography and climate, and η_{it} is the idiosyncratic unobserved error component. For the models that address the total county area in cropland, we utilized lagged (one season) values of the weather and water supply measures.

[12] We include six different clusters within our analysis: Panhandle counties, the southwest, the Magic Valley, the east, the southeast, and the Clearwater. On average there are seven counties within each cluster, with a minimum of five and a maximum of ten.

IV. Results and Discussion

Water Supply, Water Rights Distribution and Irrigated Agriculture

Table 2 presents the impact of the inter-annual volatility of total water supply and the in-season distribution of stream flow observations on the total cropland planted in a county. We expect that counties that experience high levels of seasonal water supply (measured by the ratio of the total seasonal water supply to the long term average total seasonal water supply) as well as those with access to irrigation water during the often water-short summer months will plant more crops. As shown in all models presented in Table 2, in our sample of counties from Idaho, the seasonal water supply (Lagged %WS Total) and access to irrigation water during hot summer months (Lagged %WS Late Season) are both positively correlated with the total cropland planted in the next year's growing season. All models presented include controls for the acreage of water rights held within each county—both surface and ground water, and include other controls such as total annual precipitation, average annual temperature, hydrologic basin fixed effects, and census-year fixed effects.

An important result we note is that access to late season irrigation water has a statistically significant impact on the cropland acres planted in most of our models. Only when we introduce a water supply volatility measure—estimated using a coefficient of variation for surface water supply, as shown in models (2) and (4) in Table 2, the late season irrigation water supply loses its statistical significance. The water supply volatility measure is statistically significant and has a negative impact on total cropland acres planted in the next year's growing season. Thus, our results in Table 2 show that seasonal water supply, specifically access to late season irrigation water, is very important in influencing the total cropland planted. When there is an increased volatility in the supply of surface water for irrigation, which likely manifests as a decline in late season surface water availability, the total planted cropland acres decline (the volatility in water supply variable is negatively correlated to late season water supply availability, with a correlation coefficient of -0.296).

Additionally, our results indicate the significance of farmers having access to surface and ground water rights on cropland decisions. We find that both measures of water rights access—total surface water rights acres and total ground water rights acres as a share of each county surface area, have positive and statistically significant impacts on total cropland acres planted. Thus, in Idaho over the years, county-level increase in crop acreage came from farmers who held either surface or ground water rights. Our variable measuring the ratio of total ground water rights acreage to the total surface water rights acreage indicates the importance of the ground water rights in cropland decisions. Although senior surface water rights holders usually have access to late season water supply and are therefore less susceptible to the volatility in surface water supply, ground water rights holders are more likely to have access to a more consistent and reliable water supply throughout the growing season, especially when compared to surface water rights holders without seniority. It is worth noting that the electrification of the rural farm (during the early 1930s) resulted in the development of irrigation practices away from surface water and towards groundwater as the major source of new irrigation water supply in Idaho. This evolution enabled irrigated agriculture on lands with high quality soils that lacked the necessary access to irrigation water. As a result, the farms that were more likely to use groundwater supplies became less impacted by year-to-year climatic variability and inter-annual water supply volatility, and thus began to plant crops on a more regular basis (Xu and Lowe, 2014). In models (5) and (6) in Table 2, we include variables that control for the variation in surface water right priority dates from the mean surface water priority date within each county, and note that higher variation in the vintage of surface water rights in a county leads to increased total cropland acres. Although high variations in institutions such as water rights distribution may generally have negative impacts, *at a county level* the higher variation in the vintage of surface rights appears to indicate more reliable and consistent access to water supply within a county.

Next, we investigate the impact of water supply volatility and the influence of water rights distributions on the successfully harvested cropland acres relative to planted cropland in each county. According to Table 3, it is the access to irrigation water during the hot summer months (%WS Late Season) that matters most to the acres harvested. In all models presented in Table 3, the late season water supply availability has a large, positive, and statistically significant impact on cropland harvested, but the impact of the seasonal water supply (%WS Total) is insignificant. Moreover, as shown in Model (5) in Table 3, the impact of volatility of water supply (COV WS) on harvested acres is statistically significant and negative as predicted.

We find that having access to surface and ground water rights is very significant in having successfully harvested acres in addition to the cropland decisions. Again, both measures of water rights access—total surface water rights acres and total ground water rights acres, have positive and statistically significant impacts on the harvested acres. However, the ratio of total ground water rights acreage to total surface water rights acreage no longer has a significant impact on the successfully harvested acres (although in models (2) and (4), the ground-to-surface water rights acreage ratio is positive and statistically significant when the other water rights variables are not included as controls). This result may imply that having access to a reliable and consistent water supply provided through ground water rights matters more to the cropland decisions, and the success of the harvested acres depends more on the availability of water supply in any season—as determined by any type of water rights. In models (3), (4) and (5) in Table 3, we again include a variable that controls for the variation in surface water right priority dates relative to the mean surface water priority date within each county, and find that higher variation in the vintage of surface water rights has a positive and significant impact on the harvested acres. Thus, increased variation in the vintage of surface water rights in a county indicates a consistent and relatively more reliable access to water supply within a county, which results in an increase in cropland acreage decisions at the county-level as well as more successful harvested acres.

Finally, we are interested in investigating the impact that the water supply availability and volatility as well as the water rights distribution had on per acre farmland values. In order to empirically investigate this impact on farmland value, we estimate models with the farmland value is the dependent variable where we normalize the total farm value per acre using 1984 as the base year. A significant result presented in Table 4 is that the significant impact of water supply on farmland values is through the water rights distributions in Idaho counties. Specifically, total surface water rights acres and total ground water rights acres are positive and statistically significant in determining the farmland values. Moreover, the significance of ground-to-surface water rights acreage ratio indicates the importance of having access to consistent and reliable water, through ground water access, on average farmland values.

When new water supplies become available, through proliferation of ground water or construction of new dams, the mean value of the farmland in a county may not always increase; the impact of the new water supply depends on the water rights distribution and most importantly on the quality of the lands that are made available to agricultural production after the water becomes available. In an earlier paper, we found that the presence of a dam had a positive but non-significant effect on the value of farmland (Hansen et. al. 2014), and argued that the development of marginal agricultural lands may have contributed to this outcome. These lands may have had lower returns, which in turn reduced the average productivity per acre per farm and eventually lead to decreases in the long-run average farmland value. In that case, the new water supplies were likely allocated to *new* farms on marginal lands with junior surface water rights, and the per acre yields were below those of the existing (senior) water users, and thus the mean value of the farmland tended to decrease. With ground water, although the water rights are more junior relative to those *existing* farms with senior surface water rights, the access is more reliable and consistent, and thus, ground water rights likely have a significant impact on the average farmland values.

V. Conclusion

This study is an important first analysis as it suggests that future analyses of the impacts of climate change on agricultural in arid regions should focus less on precipitation and more on the water supply availability, including the timing and runoff characteristics of the precipitation as well as the snowpack levels and earlier snowmelt-driven streamflow. Rain-on-snow events that reduce the snowpack and lead to an earlier increase in runoff, when it is less useful for irrigators, show up as aggregate increases in total annual precipitation, even though they could be detrimental to agricultural operations. Agricultural production in arid West relies more on the late-season availability of the snowpack runoff and not as much as on aggregate runoff, particularly when man-made storage facilities aren't sufficiently available. Moreover, these results may have implications for future adaptation or behavioral modifications that result from increased water trading or the use of water markets. Climate change reflects a long-term trend and adaptation and mitigation efforts take time to show their effects. Thus, utilizing historical agricultural data may provide insight on what some of the future outcomes may be.

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Table 1: Descriptive Statistics

Variable (Dependent)	sd	mean	min	max	calculation
FAVAL	438.59	557.77	33.33333	2952.61	Dep Var: Real Farmland Value / Acre ($1984)
Total Cropland	15.23	17.33	0.05	65.06	Dep Var: (Total Cropland Acres / Total County Acres)*100
% Harvested	13.77	70.20	20.02	98.64	Dep Var: (Total Acres Cropland Harvested/Total Acres Cropland)*100
Variable (Independent)					
% WS Total	0.36	1.00	0.01	2.35	% of the long run average water supply = season total / long run average season total
% WS Late	0.07	0.18	0.02	0.32	% of the total annual water supply that was delivered in july, august and september = within season july + august + september / annual total
% Surface Water	0.71	0.44	0.00	3.15	Total surface water right acres / total county area in acres
% Groundwater	0.48	0.16	0.00	3.91	Total groundwater right acres / total county area in acres
Ground-to-Surface Ratio	116.35	14.90	0.00	1356.29	Total groundwater right acres / total surface water right acres
Precipitation	9.02	21.76	5.50	49.45	total precipitation during the crop year (inches)
Temperature	3.14	44.28	36.63	52.63	average monthly temperature over the crop year (degrees Fahrenheit)
WR 1SD/N	0.11	0.69	0.46	1.00	(the number of surface water rights within one standard deviation of the mean surface water right priority date) / (the total number of surface water rights)
COV WR	0.36	1.13	0.27	2.10	100 * (the standard deviation of the surface water right priority date) / (the mean surface water priority date)
COV WS	31.48	81.05	9.71	157.41	100 * (the standard deviation of the within-season monthly water supply total) / (the mean within-season monthly water supply)

Table 2: Fixed Effects Models of Total Cropland

Model:	(1)	(2)	(3)	(4)	Marginal Effect	(5)	Marginal Effect	(6)	Marginal Effect
Lagged %WS Total	1.1094 (1.1123)	0.0263 (1.2591)	1.0266 (1.1132)	-0.0755 (1.2579)	-0.03	0.8753 (1.1157)	0.32	1.1207 (1.0936)	0.41
Lagged %WS Late Season	23.8278 (7.0716)***	11.0517 (9.0023)	23.5495 (7.0538)***	10.4173 (8.9706)	0.76	26.5499 (7.4331)***	1.93	16.4297 (6.9344)**	1.19
% Surface Water	11.1247 (0.5257)***	11.1117 (0.5481)***	10.9381 (0.5140)***	10.9413 (0.5367)***	7.74	10.8878 (0.5075)***	7.71	11.9607 (0.4953)***	8.47
% Groundwater	6.2250 (1.0774)***	6.6208 (1.1148)***	7.8344 (0.6572)***	8.0910 (0.6696)***	3.88	6.3444 (1.0000)***	3.04	6.2103 (1.0496)***	2.98
Ground-to-Surface Ratio	0.0082 (0.0035)**	0.0074 (0.0036)**				0.0074 (0.0033)**	0.86	0.0108 (0.0035)***	1.26
COV WS		-0.0455 (0.0156)***		-0.0469 (0.0155)***	-1.48				
WR 1SD/N						13.0987 (4.2412)***	1.38		
COV WR								12.9809 (2.5042)***	4.68
Lagged Precipitation Total	0.3996 (0.1355)***	0.4246 (0.1368)***	0.4022 (0.1358)***	0.4276 (0.1370)***	3.86	0.4028 (0.1334)***	3.63	0.3495 (0.1335)***	3.15
Lagged Temperature Average	2.7542 (0.3507)***	3.0050 (0.3571)***	2.7476 (0.3517)***	3.0069 (0.3580)***	9.44	2.9026 (0.3512)***	9.11	2.2295 (0.3501)***	7.00
Observations	829	825	829	825		829		829	
R-squared	0.61	0.61	0.60	0.61		0.61		0.62	

Robust standard errors in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Note: All models include hydrologic basin fixed effects and time (year) fixed effects

Dep Var: Total Cropland (% of total county acreage)

Table 3: Fixed Effects Models of Percentage of Total Cropland Harvested

Model:	(1)	(2)	(3)	(4)	(5)	Marginal Effect
%WS Total	-0.9028 (2.0730)	-0.4890 (2.0856)	-0.9681 (2.1271)	-0.5493 (2.1225)	-1.9878 (2.0932)	-0.72
%WS Late Season	30.6238 (9.6186)***	42.7305 (9.2960)***	27.3189 (9.8756)***	41.3966 (9.4662)***	17.2398 (10.2307)*	1.25
% Surface Water	1.8360 (0.5777)***		2.2350 (0.6002)***		2.2269 (0.6012)***	1.58
% Groundwater	6.6602 (1.0997)***		6.6247 (1.0943)***		6.6631 (1.0956)***	3.20
Ground-to-Surface Ratio	-0.0029 (0.0034)	0.0135 (0.0020)***	-0.0016 (0.0034)	0.0142 (0.0021)***	-0.0015 (0.0034)	-0.17
COV WS					-0.0425 (0.0179)**	-1.34
COV WR			6.2501 (2.8765)**	4.3801 (2.7846)	6.7781 (2.8183)**	2.45
Precipitation Total	0.0888 (0.1434)	0.0011 (0.1403)	0.0664 (0.1464)	-0.0104 (0.1422)	0.0759 (0.1448)	0.68
Temperature Average	1.9809 (0.4488)***	2.3290 (0.4298)***	1.7327 (0.4811)***	2.2178 (0.4457)***	1.9351 (0.4898)***	6.07
Observations	803	803	803	803	799	
R-squared	0.41	0.38	0.41	0.39	0.42	

Robust standard errors in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Note: All models include hydrologic basin fixed effects and time (year) fixed effects

Dep Var: % of Total Cropland Harvested

Table 4: Fixed Effects Models of Farmland Value per Acre

Model:	(1)	(2)	(3)	(4)	Marginal Effect
%WS Total	71.0161 (58.3358)	66.6250 (61.0360)	68.0058 (58.2588)	64.4727 (55.4019)	23.30
%WS Late Season	228.6926 (218.5821)	967.4867 (199.2010)***	231.4537 (217.7129)	-1.4889 (217.0160)	-0.11
% Surface Water	196.8185 (25.0436)***		187.2211 (24.5056)***	222.8699 (24.3963)***	157.74
% Groundwater	25.8585 (26.9203)		104.3189 (22.0634)***	23.6895 (25.2053)	11.37
Ground-to-Surface Ratio	0.3950 (0.1075)***	0.3563 (0.0736)***		0.4886 (0.1051)***	56.85
COV WR				425.4410 (62.6674)***	153.51
Precipitation Total	6.0392 (3.9025)	8.8930 (3.9805)**	5.8559 (3.9085)	4.3339 (3.7336)	39.08
Temperature Average	58.2063 (12.2168)***	102.9320 (12.6930)***	57.3349 (12.2599)***	41.5516 (12.2766)***	130.39
Observations	851	851	851	851	
R-squared	0.67	0.61	0.66	0.69	

Robust standard errors in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Note: All models include hydrologic basin fixed effects and time (year) fixed effects

Dep Var: Farmland Value per Acre