Climate Variability and Water Infrastructure: Historical Experience in the Western United States

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Abstract
Greater historical perspective is needed to enlighten current debate about future human responses to higher temperatures and increased precipitation variation. We analyze the impact of climatic conditions and variability on agricultural production and flood control in the western states, which are characterized by the continent's driest and most variable climate. We have assembled county-level data on dams and other major water infrastructure; agricultural crop mixes and yields; precipitation and temperature; soil quality, and topography. Using this extensive data set, we analyze the impact of water infrastructure investments on crop mix and yields and the incidence of floods in affected counties relative to similarly-endowed counties that lack such infrastructure. We anticipate that water infrastructure will smooth agricultural crop mixes and output, and reduce flooding. In addition, we explore the political economy of the Reclamation Act of 1902 to cast light on how politics and climatic factors may influence contemporary investment decisions.

I. Introduction

There is a growing literature on climate change (Stern, 2007; Nordhaus, 2007; Weitzman, 2007 and references therein). Agriculture is particularly vulnerable. For the U.S. the estimated impacts are often mixed, with findings of nonlinearities in key commodity yields beyond threshold temperatures; predictions of higher profitability for US agriculture; and reports of high adjustment costs (Mendelsohn, Nordhaus, and Shaw, 1994; Cline, 1996; Kelly, Kolstad, and Mitchell, 2005; Schlenker, Hanemann, and Fisher, 2006; Deschenes and Greenstone, 2007; Schlenker and Roberts, 2008). These studies generally rely upon contemporary data. Greater historical perspective, however, would enlighten current debate about the effects of climate change and future human responses to it. Indeed, the expansion of agriculture across North America in the 19th and 20th centuries encountered greater climatic variation than is predicted in current climate change models (Olmstead and Rhode, 2008). Accordingly, analysis of how those conditions were addressed and the impact on crop mixes and agricultural production can provide valuable information for addressing current climate variability. This study adds to the literature on adaption to climate fluctuation and change.

Much academic and policy concern has been focused on mitigation of potential climate change through international efforts to control greenhouse gas emissions, such as the Kyoto Protocol, or to national policies to implement cap and trade programs or to shifting energy production toward less-polluting sources, such as wind and solar power. Adaptation has received somewhat less attention. Yet, it is increasingly evident that adaption must be given more consideration because the stock of greenhouse gasses may result in climate change regardless of mitigation efforts and because of the vulnerabilities of many of the world's poorest societies. As Nordhaus observed, "mitigate we might; adapt we must."(Pielke, 1998).

The IPCC (2001) defines adaptation as the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities." We are examining planned adaptation that involves deliberate policy decisions in reaction to possible changes in conditions. Our concern is with water resources and the investment in infrastructure for irrigation that could mitigate the effects of more variable precipitation and drought on agricultural production. Food security is a major concern, mostly in developing countries that depend on local agricultural production for most supplies (Lobell et. al., 2008). Water resources may be particularly hard hit by climate change, especially in semi-arid and arid regions, where water resources are already scarce (Collier et. al., 2008; Francisco, 2008). A large body of work discusses both mitigation and adaptation strategies to changes in water resources that may be brought on or exacerbated by climate change (Brekke et. al., 2009; Collier et. al., 2008; Easterling et. al., 2004; USEPA, 2008).

Agriculture is particularly sensitive to changes in water supplies. Studies tend to concentrate on individual decisions of crop type, planting and harvest time or irrigation choices and not on infrastructure investment (Herminia, 2008, Kurukulassuriya and Mendelsohn, 2008; Mendelsohn and Seo, 2007; Quiroga and Iglesias, 2007). Much work pertaining to infrastructure investment centers on developing nations (Heyden and Pegram, 2007; USAID, 2007), or is not directly related to water resource and irrigation (Hikel et. al., 2003). Those studies involving water-related infrastructure tend to concentrate on damage to those structures from extreme weather events (MacGill et. al., 2003; Kingwell, 2006) or improving existing infrastructure (Kahn et. al. 2008; Quiggin and Horowicz, 2003).

Water infrastructure investment in the United States in the 20th century to address semi arid conditions and drought provides a natural experiment to assessing the impact of such policies on agricultural production. The land west of the 100th meridian is North America's driest and most variable (Lettenmaier, et al., 2008). Further, there is an indication of increases in the duration and severity of drought in western regions (Andreadis and Lettenmaier, 2006). Concerns about such variability of water supply in the West are not new – much of the present water supply infrastructure was constructed in the late 19th and early to mid 20th centuries due to historical demand for agricultural irrigation, flood protection, drinking water, and hydroelectric power. The extent to which this investment assuaged the impacts of climate instability is a focus of this study. Using historical county-level data for the western states, we examine if and how the water supply infrastructure stabilized agricultural production during droughts (and provided flood protection during floods).

We are constructing an integrated dataset on water supply and water infrastructure in the states west of 100th meridian. This county-level data set potentially includes details on all major constructed dams and canals as well as aquifers and river networks. We have 2,140 dam observations from 1870-2002 and 6,004 rivers and streams observations, as well as data on 233 major canals and aqueducts, to be merged in the dataset. This extensive dataset accounts for the entire major water supply and water distribution infrastructure in the western United States. The water infrastructure dataset is spatially linked to topographic characteristics, historical climate data, historical agricultural data, and historical population data at the county-level using GIS, U.S. Census, and other data sources. We use these data to analyze the impact of the water infrastructure on agricultural production, and on flood control. We expect that counties that had water storage and distribution were better able to deal with annual and decadal climatic variability. Farmers with access to more consistent water supply were more likely to smooth agricultural production (crop mix and yields) during drought. Counties with flood control were better able to mitigate flood losses relative to similar counties without such infrastructure.

II. Origins and Impact of Western Water Infrastructure

During late 19th century, as agricultural settlement of North American moved into the Great Plains and beyond, irrigation expansion and flood control became crucial issues. The agricultural techniques and practices settlers brought with them from the humid East were not applicable in the arid or semi-arid West. Institutions such as the 1862 Homestead Act that created 160 to 320 acre small farms were not appropriate in the region (Libecap and Hansen, 2002). As early as the 1870s John Wesley Powell was promoting organization of autonomous irrigation districts to promote cooperation among farmers and to cope with the externalities associated with each individual farmer's decision on water storage and distribution.

Much interest in federal reclamation program to construct dams and canals to store and distribute water developed after individual, corporate and state attempts to deliver such infrastructure was found to be inadequate. Many state attempts, such as the 1887 Wright Act of California, faced problems ranging from poor construction to creation of fraudulent irrigation districts and huge debts (Robinson, 1979). Most private irrigation projects failed, and those that succeeded were of small size due to problems with free-riding. After much debate and failed attempts to develop water infrastructure in the West, the Federal Reclamation Act was passed in June 1902 and a revolving Reclamation Fund was created to finance water infrastructure projects, funded through sales of public lands and cost sharing by recipients (Pisani, 2002). The title for the water infrastructure remained with the federal government, and state and territorial agencies, as well as local water supply organizations, such as irrigation districts, governed the use and the distribution of water (Robinson, 1979). This structure mostly remains in place today.

We analyze the impact of the water infrastructure on agricultural production and flood control across time using historical agricultural and climatic data. The specific research questions we seek to answer are:

- Were counties that had irrigation water supply and distribution infrastructure better able to cope with the problems of short-term climatic variability (either due to natural variability in the hydrologic cycle or due to disruptions of the cycle), relative to those similar counties without such infrastructure?
- Did cropping patterns (measured in area of irrigated and harvested land, relative to total agricultural land) display less variation after the construction of irrigation water supply and distribution infrastructure?
- After controlling for technological and biological innovations, did agricultural productivity (measured in crop-specific tons/acre or bushels/acre,) display less variation after the construction of irrigation water supply and distribution infrastructure?
- Were the problems related to flooding in flood prone counties lessened after the construction of dams designed for flood control?

To address these questions, we examine the variation in agricultural production before and after dam and canal construction at the county level as well as across counties with and without such infrastructure. Counties with access to water infrastructure are expected to experience less agricultural production failures after recent unfavorable climatic conditions, all else equal. We also examine the variation in agricultural production in normal and in drought periods across time.

In addition, w explore the political economy of the timing and structure of the Federal Reclamation Act of 1902, examining congressional voting patterns as a function of political factors (political party, membership on key congressional committees), economic and demographic variables (past agricultural output, population change, private irrigation organizations), and natural factors (drought and flood patterns, water sources, soil quality, topography in proponent regions). Our objective with this analysis is to better understand the underlying factors that influenced the enactment of federal legislation and the distribution of water supply and flood control projects made under it. As part of this analysis we are collecting information from state and national archives on irrigation and drainage enterprises, their levels of investment, and the reasons for their alleged failures in providing water infrastructure in the West, all of which underscore the pressure for government intervention in the provision of public water infrastructure. The research questions to be examined are:

- What explains the timing of the Reclamation Act of 1902 and the distribution of projects authorized by it?
- Were some suitable areas missed or had projects that were developed much later?

This analysis requires examination of congressional voting patterns in the 57th as well as earlier and subsequent Congresses on the legislative history of the Reclamation Act of 1902 (P.L. 57-161, 32 Stat. 388). We are collecting data on House and Senate votes on this law, the characteristics of key state constituencies that could be affected (past agricultural output, membership in Irrigation Congresses, private water supply organizations), political party, state climatic variables (dryness, precipitation variability), opportunity to expand agriculture (topography, soil quality), location of natural water sources—rivers, past population growth, membership of representatives in key congressional committees, agricultural prices, and other variables. We seek to explain why this law with such important long-term consequences (that we are exploring) was enacted when it was and why irrigation and flood control projects were placed where they were.

III. Data Sources and Description:

Two objectives of this research are a) to examine the impact that the water supply infrastructure has had on agricultural productivity and protection from floods at the county level, across time; and b) to understand the role of political and other factors in explaining the timing and nature of the 1902 Federal Reclamation Act and the observed pattern of construction of major water projects under it.

In order to address these questions, we have constructed (and in the process of expanding) a spatial panel of climate, agriculture and infrastructure projects in the western United States, from 1870 to 2002. Specifically, we have gathered information on dams and the water distribution network in the west from the National Inventory of Dams, county-level agricultural census data measured every five to ten years from the 1870-2002 United States Census of Agriculture**,** and annual temperature and precipitation data from the United States Climate Division dataset**.** Because the data sources are provided at three very different spatial scales, the integration of the data poses some empirical challenges. The next several sections present a more detailed discussion of the data sources and discuss the methods used to overcome the temporal and spatial issues.

A. Major Water Infrastructure:

Our primary source for the dam data is U.S. Army Corps of Engineers, National Inventory of Dams (NID). This data source includes information on the location, owner, the year of construction completion, the primary "purpose" of construction as well as capacity and height characteristics of dams. The primary purpose of construction includes flood control, debris control, fish and wildlife, hydroelectric, irrigation, navigation, fire protection, recreation, water supply, and tailings control. Figure 1 shows a map portraying major dams in the western United States based on NID, and Table 1 summarizes the descriptive statistics of these major dams across time.

About 43% of the dams in the west were constructed with irrigation as the primary purpose. Dam construction in the west peaked in the post-WWII period – the 1960s and 1970s. Over 55% of the total dam capacity in the Western United States was added in the 1950s and 1960s (see Table 1).

We supplement the dam data set with spatial data on major aqueducts, canals and water systems in the Western United States. Thus, we will link all counties that have access to dam water through a canal system. The primary source for this data is U.S. National Atlas Water Features (USGS).

B. Census of Agriculture Data:

We use the U.S. Census of Agriculture to obtain several different measures, including: total farm land; total cropland and total harvested cropland; irrigated and non-irrigated acreage by crop; tonnage or bushels by crop. In addition, we obtained major crop variables such as wheat and hay as well as those that are state/region specific in the west, such as potatoes in Idaho, and sorghum in Colorado. Much of the data are available via ICPSR (The Interuniversity Consortium for Political and Social Research). Other data, however, are manually inputted from historical hard-copy manuscript censuses and published censuses.

C. Climate Data:

The U.S. Climate Division Dataset (USCDD) provides averaged climate data based on 344 climatic zones, covering 1895-present. The USCDD dataset includes temperature and precipitation measures, including the monthly maximum, minimum, mean temperatures and total monthly precipitation levels. In addition, it includes other related variables such as Palmer drought severity indices (PDSI) and standardized z-scores of temperature and precipitation. The PDSI is a long-term drought measure that is standardized to the local climate so it shows relative drought and rainfall conditions in a region at a specific time. It uses temperature and rainfall information in a formula to determine dryness. The Palmer Index is most effective in determining long term drought—a matter of several months. It uses a 0 as normal, and drought is shown in terms of negative numbers. Unfortunately, it is not particularly useful in calculating supplies derived from snowpack sources.[1]

D. Topography, Soil Quality and Flood Occurrence Data Sources:

We utilize a large-scale topographic classification from The National Atlas (USGS) which assigns each county in the United States to one of 21 different land-surface types. The major classes include plains, tablelands, open hills and mountains. Within each major class there are four to five sub-classifications. The dataset land-surface classification is based on two major properties: the slope (inclination) of the land, and the elevation of the land (relief).

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[1] The Climatic data is 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.

We supplement the topographic classification data with soil-type data from the U.S. Department of Agriculture, Natural Resources Conservation Service. This dataset provides county-level measures of the Non Irrigation Capability Class (NIRRCAPCL), which is the broadest category in the land capability classification system for nonirrigated soils. Flood occurrence and damage data will be collected from the USGS and from the National Weather Service. This data, which covers the 1926-2003 years, will provide the location of the flood, and estimates of the present value of damages due to the flood. These data are currently available at the drainage basin and river level.

E. Census of Irrigation and Drainage

In 1930, the Census of Irrigation and Drainage surveyed 75,517 irrigation enterprises and 67,927 drainage enterprises. The information collected in the irrigation schedules of the Census included the exact location and management of the enterprise, source of water supply, number of acreage included, cost of operation, source of water, nature of water rights, description of works (including date of construction, number and type of dams, canals, and pipelines, and number and type of wells and pumps), land irrigated or covered by the enterprise, capital invested in the enterprise, cost of maintenance and operation, and drainage activities on the irrigated lands. Information collected in the drainage schedules included the location, management, type (or class) and purpose of the enterprise, the land acre covered, the amount of capital invested and type of financing, the nature of the drainage works (including the extent of ditches, levees, and drains and the number and capacity of pumps), and the cost of operation and maintenance. The published version of these records, aggregated to the county and state level, appear in U.S. Census Bureau, *Fifteenth Census of the United States*, Vol. 1. *Irrigation of*

Agricultural Lands. The manuscript version of the original enterprise forms exist in the National Archives in Washington, DC. We plan to collect the data at the National Archives and use these very detailed individual-level records to investigate how the water supply organizations operated, and to supplement our analysis of the pattern of water infrastructure projects throughout the West.

F. Data Sources on Political and Demographic Variables:

We are in the process of collecting data from the state congressional records on political factors such as political party and membership on key congressional committees by publicly-elected officials who may decide on funding for these projects. In addition, we are gathering information from memorials to congress and congressional debates to better evaluate the role played by such political figures.

In addition, we have collected data on county-level demographic characteristics including population and income trends, past agricultural output and where possible, regional electricity, water and commodity prices. Data on many of these demographic variables are available from the various years of the Population and Agricultural Censuses. For other data on regional characteristics, we will contact state resources. We will also collect data on the number of private irrigation organizations and their regional investment levels. Such data is available from the 1930 Census of Irrigation and Drainage survey as outlined above.

G. Data Matching Process

Assignment of Water Supply to Counties

Because we are concerned with the impact of major water infrastructure on agricultural productivity, correctly connecting the available water supply with the agricultural demand is essential. In order to do so, all of the major dams, canals, aqueducts and river systems in the west have been spatially merged with the county-level agricultural census data within a geographic information system (GIS). In our initial empirical specifications, we assume that a county has access to water from a major dam if the dam falls within a county, or within a certain distance from the county.[2] We assign these counties the supply of dam water (measured in both volume of water and the number of irrigation dams that the county has access to) for all subsequent years after dam completion.

Many major water infrastructure projects and river systems are shared by multiple counties and multiple states. In these cases, water supply will be assigned to a county if it has any form of major water infrastructure flowing through it or along its boundary, down-stream (canal, or aqueduct,) from the major dam. In those situations where river systems and aqueducts are many hundreds or thousands of miles in length (such as the Colorado or the California Aqueduct,) and have multiple dams on the same river, water supply will be assigned to those counties that are down-stream from the dam, before the next dam. In the preliminary empirical analyses discussed below, we use only dams assigned to counties or within a certain distance from a county.

Assignment of Agricultural Data to Counties

There are two major issues with the integration of agricultural data into our analysis: the changing shape of counties over time, and the changing measures or definitions within the agricultural data. First, because the agricultural census is provided at the county level, and

[2] For all of the major dams in the Western United States, we are contacting the dam operator or parent company to establish a baseline of the counties that are allocated water from the dam. Because we are unable to account for changes over time in this allocation, we will assume that the present allocation is uniform across all years that the dam has been in operation.

county boundaries have changed over time, we have normalized the census data to current 2000 census county boundaries. We multiplied the historical census count data (measured in acres or volume of output,) by the fraction of the county that lies in the current 2000 census county boundary definition (measured as the percentage of the total land area). In almost all cases the historical county boundaries were subdivided into current boundaries, with very few modifications.[3]

Second, the crop acreage and harvest data within the census has changed over time. Data on irrigation acreage was first available in the 1870 agricultural census, but didn't reappear until the 1900 agricultural census. Similarly, in the early years of the agricultural census, certain forage crops were listed as a single entry, but in future years the forage crops were split into multiple categories such as hay, alfalfa and clover. We are limited by the lowest common denominator in these cases. In the models in which we are interested in individual crops that have been further divided into sub-crops, we aggregated so that the unit of measure is consistent across all of the years of our sample.

Assignment of Climate Data to Counties

The climate data that we will use in our models is available from the United States Climate Division, and includes zonal temperature and precipitation data which is available across all of the years in our sample. This dataset divides each state into similar climate zones – of which there are 388 in the United States. The zonal climate data utilize all of the monitor readings within a zone to arrive at zone-averaged temperature and precipitation measures.

[3] For example, in Idaho, Alturas County, which existed from 1864 to 1895, was divided over the years into 8 separate counties. The transition to 8 counties was not instantaneous – therefore the number of counties is often different across different Agricultural Census periods. As a robustness check, we have conducted an identical analysis and omitted all counties that had changes in geographies over time; the results are consistent with those from the full 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 data to counties that overlap multiple zones, within a GIS we average the zonal climate data across the overlapping counties.[4]

IV. Econometric Analysis:

In order to measure the impact of the major water infrastructure on the agricultural harvest and on flood control, we let $H_{j,t}$ denote the total agricultural harvest (measured in crop yields per total cropland, and cropland harvested per total cropland,) or the occurrence of a major flood event, in county *j* in year *t*. Our basic econometric model is equation (1) below:

$$H_{j,t} = \alpha D_{j,t} + X_{j,t}\beta + \theta_t + \delta_j + \eta_{j,t} \tag{1}$$

where α is the parameter of interest, and measures the difference in the harvest or the number of flood events, between counties with and without major water infrastructure projects. If we allow $H_{j,t}$ to represent 1) individual crop variability before and after a major water infrastructure project is completed, or 2) the percent of the crop that is successfully harvested before and after a major water infrastructure project is completed, or 3) the magnitude and cost of flooding events before and after a major water infrastructure project is completed, we will address research questions 1-4. Formally, α represents the average treatment effect of the water infrastructure, and is given by:

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[4] 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 zones, 1 overlaps with 4 climate zones, and 1 overlaps with 5 climate zones. As a robustness check, we also run models with only those counties that are comprised of a single climate zone.

$$\alpha = \mathrm{E}[H_{j,t} \mid D_{j,t} = 1; X_{j,t}] - \mathrm{E}[H_{j,t} \mid D_{j,t} = 0; X_{j,t}] \qquad (2)$$

In order to correctly represent the impacts of climate on the harvest, we use a one-year lag for the time-variant controls.[5] In addition to measuring the presence of major water infrastructure ($D_{j,t}$) as a binary variable, we also allow the measure to scale, representing both the number of infrastructure projects that the county *j* has access to in year *t*, and the *volume* of water available from major water infrastructure projects to county *j* in year *t*.

A. Definition of Arability and Description of County Matching Process

A major problem with the econometric strategy above is that water infrastructure and irrigation availability could have brought on agricultural production in the areas where agricultural production was not possible without irrigation, and thus, introduce potential endogeneity issues. In order to address this problem, we use a definition of "arability" based on possible profitable production of crops without irrigation on land with low average and highly variable rainfall, and match counties in our sample accordingly. We then exclude all counties in our sample where profitable agricultural production without irrigation would not be possible.

The definition of arability used includes minimum average rainfall of 10 inches per year; sufficiently deep soil with no clay and sand; and no excessive evaporation due to wind and heat during critical stages of plant growth. We match the counties based on similarity in climate and topography and control for the soil differences and evaporation (temperature) in the estimated models.

In order to match counties based on similar climate and topography, we make use of two datasets. First, the U.S. Climate Division Dataset (USCDD) provides averaged temperature and

[5] The agricultural output is most significantly impacted by the climate in the year leading up to the harvest. It is unlikely that historical climate perturbations (>1year) may impact future harvests; we address this possibility in the robustness checks.

precipitation measures based on 344 climatic zones, covering 1895-present. This data was used to produce a dataset of the 112-year averages and standard-deviations for annual temperature and precipitation levels, as well as spring-summer temperature and precipitation levels for each county in the Western United States. Second, the National Atlas (USGS) dataset of land surface types, which identifies topography codes for all western counties. This dataset provides general land-surface types that are divided into 21 different groups, ranging from "flat plains" to "high mountains".

Counties were grouped based on one of the 21 topography codes. Within each of the 21 topography codes, counties were ordered by annual average precipitation. A bandwidth of a single standard deviation of annual average precipitation within each topography classification was added to, and subtracted from, the annual average precipitation. Counties that fell within the same topography type *and* the same annual average precipitation bandwidth were assigned to a cohort. This cohort then rechecked to verify whether it was also within the bandwidth of one standard deviation of annual average temperature. Our matching rule then was primarily based on topography and average precipitation and secondarily on average temperature levels. This matching process created 27 classes of counties. As shown in Table 2A, the average annual precipitation within classifications ranges from 10 inches (class 13) to 36 inches (class 7). This table also summarizes mean annual wheat production and share of crop failure within each classification.

The USCDD also identifies topography codes for five general land surface types: Plains, Tablelands, Plains with Hills or Mountains, Open Hills and Mountains, Hills and Mountains. The previous process in which precipitation bandwidths were ordered within 21 topography codes was condensed to produce bandwidth groupings within the 7 land surface types. As before, counties that fell within the same condensed topography code *and* the same annual average precipitation bandwidth were assigned to a cohort. Thus, we created 8 county cohorts based on a more aggregate measure of topography and precipitation and temperature averages within these broader categories. Table 2B shows descriptive statistics based on these broader cohorts of counties. The mean average annual precipitation ranges from 14 inches (cohort 6) to 36 inches (cohort 4).

V. Results from the Preliminary Analysis:

One major focus of this study is the impact of the major water infrastructure on agricultural production. We hypothesize that counties, which are included in the water supply and distribution infrastructure, are better able to deal with the problems of short-term climatic variability (either due to natural variability in the hydrologic cycle or due to disruptions of the cycle) in terms of smoothing out agricultural production over time relative to those similar counties without such infrastructure. One such preliminary analysis is conducted for the state of Idaho. Table 3 provides these results. Model (1) shows that for each additional dam constructed in a county, the wheat production per harvested acre of wheat increases. We looked at wheat production because it was most consistently available over the years and because it did not require irrigation for production unlike potatoes, the major crop of Idaho. Similarly in Model (2), the larger the water volume available through dams, the higher the wheat productivity. Higher precipitation and temperature levels increase wheat productivity as well. Interestingly, lower precipitation levels increases the irrigated cropland percentage as well, suggesting a shift towards irrigation during periods of less rainfall. In addition, the results from Model (3) show that irrigation water availability increases harvested cropland as a share of total cropland.

Table 4 shows preliminary results from our matched sample during 1890 - 2002. The upper panel shows the results based on broader matching (8 similar county cohorts) and the lower panel depicts results based on more disaggregated matching (27 similar county classes). According to these estimation results, *within* similar counties, those counties with access to large water storage have significantly higher levels of wheat production, controlling for precipitation, temperature levels, drought severity index and soil quality. Specifically, wheat production is 2 to 2.5 bushels per acre is higher than the mean level of wheat production within similar cohorts when a large irrigation dam is present. Wheat production is about 1.3 bushels per acre higher than the mean levels within more disaggregated county classes. Columns (2) and (3) in both panels show the results of the impact of irrigation dam on crop failure shares. Column (2) presents results with only share of failed crop acres, and column (3) includes fallow and idle land in addition to the failed crop acres. As indicated in column (3), when irrigation dam is present share of failed cropland acres and idle/fallow land to total crop acres declines. One interesting result in our models is the negative impact of rainfall levels on wheat production within county cohorts and classes.[6] This impact is small but statistically significant, and it may be due to the matching process where within each county cohort and classification, average long-term precipitation levels are very similar.

We investigated the importance of dam size estimating models with different water storage capabilities. Table 5 shows that when we include only the larger irrigation dams in our models, the estimated impact on wheat production is larger, but dam size has negligible impact on preventing crop failure. Thus, even small irrigation dams may have an impact on reducing

[6] This result holds when we use average annual precipitation instead of spring-summer precipitation.

crop failure and idle land share, but wheat productivity impact although always statistically significant increases when a large dam is present.[7]

These basic results are suggestive that the availability of water infrastructure increases agricultural productivity and the likelihood of successful harvest as measured by harvested cropland as a share of total cropland. Therefore these results suggest that the presence of major water infrastructure has helped to mitigate the damages of periodic droughts, and will continue to do so if the climate change projections of increased duration and severity of droughts in the western regions comes to fruition.

[7] We estimated our models using any purpose dam as well as irrigation dam. Results are qualitatively similar although more significant when we use irrigation dams. We also estimated models showing the impact of dam not only where it is located, but from various distances from dam and again results were similar.

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Figure 1: Map Portraying Major Dams in the Western United States

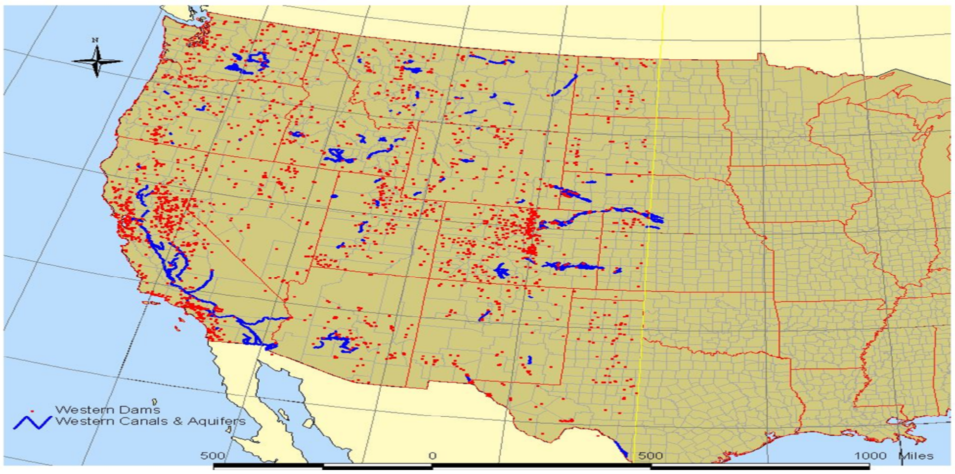

Table 1: Descriptive Statistics on Western Dams

Table 1: Descriptive Statistics on Western Dams

			Primary Purpose (%)				
Year Completed	# Dams	Storage (AF)	Irr.	H.E.	Res.	Flood	Other
Pre-1861	1	630	0%	0%	100%	0%	0%
1861-1870	3	22,327	0%	0%	100%	0%	0%
1871-1880	4	73,158	50%	0%	25%	0%	25%
1881-1890	20	466,507	60%	5%	20%	0%	15%
1891-1900	48	665,295	60%	2%	31%	2%	4%
1901-1910	134	7,935,010	60%	10%	21%	0%	9%
1911-1920	157	15,661,438	52%	25%	15%	2%	6%
1921-1930	195	11,317,853	48%	12%	24%	3%	14%
1931-1940	168	41,934,943	57%	5%	21%	4%	13%
1941-1950	150	24,443,106	61%	7%	13%	12%	7%
1951-1960	327	73,477,285	44%	13%	15%	10%	17%
1961-1970	426	65,475,873	35%	11%	18%	10%	26%
1971-1980	265	33,334,123	32%	4%	18%	18%	28%
1981-1990	189	6,835,046	29%	5%	16%	14%	36%
1991-2000	78	1,995,697	17%	4%	24%	9%	46%
2001+	1	727	0%	0%	0%	0%	100%

Table 2A: Descriptive Statistics in Matched Counties (Classifications)

Classification	Mean Annual Precipitation	Mean Annual Temperature	Standard Deviation Precipitation	Standard Deviation Temperature	Mean Annual Wheat Production	Share of Land with Crop Failure and Fallow / Idle Land	Share of Irrigated Acres	Mean Soil Quality	Topography Class
1	15.52	45.38	1.27	20.68	17.84	0.25	0.02	3.25	2
2	18.82	50.88	1.44	19.37	19.38	0.33	0.12	3.71	2
3	15.68	44.99	1.20	19.45	18.60	0.31	0.06	3.85	4
4	18.77	47.79	1.48	20.02	21.41	0.25	0.07	3.92	4
5	21.17	46.90	1.54	21.12	19.20	0.19	0.04	3.04	4
6	25.72	51.21	1.78	20.20	21.53	0.15	0.04	3.11	4
7	35.60	54.09	2.30	18.71	24.14	0.10	0.02	3.57	4
8	15.53	46.65	1.16	18.02	17.17	0.35	0.03	5.04	5
9	19.39	44.95	1.43	20.84	16.91	0.19	0.01	3.97	5
10	14.72	48.78	1.06	15.95	21.00	0.31	0.04	5.11	6
11	13.86	43.12	1.02	19.28	20.86	0.27	0.11	5.19	9
12	18.08	47.14	1.40	18.44	24.37	0.21	0.21	4.83	9
13	10.15	49.05	0.73	16.13	27.15	0.17	0.11	6.86	12
14	12.58	50.35	0.91	16.03	27.80	0.28	0.10	6.29	12
15	15.82	45.22	1.23	20.37	19.05	0.28	0.01	5.00	14
16	20.17	46.87	1.46	19.93	17.85	0.13	0.04	5.05	14
17	12.96	42.57	1.07	20.59	18.66	0.36	0.02	5.35	15
18	12.41	46.20	0.85	16.06	33.45	0.20	0.15	5.61	16
19	15.97	47.82	1.07	14.75					
20	19.97	53.09	1.85	10.89	31.02	0.20	0.09	5.87	16
21	14.88	43.17	0.92	16.61	25.33	0.21	0.13	6.00	17
22	19.25	48.93	1.47	14.26	28.64	0.14	0.11	5.66	19
23	11.55	50.19	1.05	14.81	29.50	0.19	0.19	5.93	21
24	13.68	43.86	0.94	17.20	27.43	0.18	0.14	6.36	21
25	15.48	43.32	0.90	16.70	21.79	0.17	0.14	5.83	21
26	18.60	46.33	1.27	15.28	28.10	0.14	0.17	6.12	21
27	22.13	46.73	1.57	21.63	18.65	0.13	0.07	3.12	2

Table 2B: Descriptive Statistics in Matched Counties (Cohorts)

Cohort	Mean Annual Precipitation	Mean Annual Temperature	Standard Deviation Precipitation	Standard Deviation Temperature	Mean Annual Wheat Production	Share of Land with Crop Failure and Fallow / Idle Land	Share of Irrigated Acres	Mean Soil Quality
1	17.17	48.13	1.35	20.02	18.61	0.29	0.07	3.48
2	17.22	46.39	1.34	19.74	20.00	0.28	0.06	3.89
3	23.01	48.28	1.63	20.98	19.79	0.16	0.05	3.09
4	35.60	54.09	2.30	18.71	24.14	0.10	0.02	3.57
5	16.55	46.79	1.22	18.27	18.36	0.28	0.03	4.71
6	13.67	47.42	1.01	17.47	25.05	0.23	0.13	5.79
7	16.49	46.58	1.26	16.96	24.86	0.22	0.08	5.50
8	14.83	45.92	1.04	16.00	26.70	0.17	0.16	6.06

Table 3: Preliminary Results from Idaho

Table: OLS Models of Agricultural Productivity and Composition

Dep Var:	Wheat Produced / Harvested Acres of Wheat		Irrigated Cropland Harvested / Total Cropland
Model:	(1)	(2)	(3)
Irrigation Dam (count)	4.3731 (1.7238)**		0.0821 (0.0176)***
Irrigation Dam Vol (100,000 AF)		1.4494 (0.6953)**	
Precipitation	17.7053 (2.4550)***	18.1423 (2.6041)***	-0.1763 (0.0518)***
Temperature	5.5572 (0.6118)***	5.8936 (0.6314)***	0.0135 (0.0081)
ln(Population)	10.6831 (1.5222)***	11.2337 (1.4854)***	0.3806 (0.0711)***
Observations	766	766	262
Fixed Effects (Counties)	YES	YES	YES
R-squared	0.38	0.37	0.49

Robust standard errors in parentheses; * significant at 10%; ** significant at 5%; *** significant at 1%

Note: RHV are lagged for models with harvest counts

Table 4: Fixed Effects Estimation of Wheat Productivity and Crop Failure in Matched Counties

	(1)	(2)	(3)	(4)	(5)	(6)
	wheatprod	pctcropfailure1	pctcropfailure2	wheatprod	pctcropfailure1	pctcropfailure2
>50k AF H2O Presence (Irrigation)	2.1530	-0.0082	-0.0672	2.4561	-0.0101	-0.0753
	(0.2607)***	(0.0049)	(0.0238)**	(0.2680)***	(0.0042)**	(0.0246)**
Average Spring - Summer Precipitation	-0.6573	0.0020	0.0043	-0.9385	0.0022	0.0024
	(0.1853)***	(0.0009)*	(0.0019)*	(0.2579)***	(0.0008)**	(0.0022)
Average Annual Temperature	0.2833	0.0005	0.0063	0.2095	0.0003	0.0019
	(0.1468)*	(0.0007)	(0.0011)***	(0.1357)	(0.0004)	(0.0021)
Palmer Drought Severity Index (Avg.)	0.3378	-0.0059	-0.0072	0.4255	-0.0058	-0.0070
	(0.1621)*	(0.0009)***	(0.0023)**	(0.1184)***	(0.0010)***	(0.0027)**
Average Soil Quality	0.9271	-0.0014	-0.0141	0.9020	0.0005	-0.0063
	(0.4907)	(0.0029)	(0.0072)*	(0.4382)*	(0.0029)	(0.0075)
Observations	8341	6068	5947	8341	6068	5947
Cluster Fixed Effects	8	8	8	8	8	8
R-squared	0.54	0.48	0.36	0.51	0.47	0.31
State Fixed Effects	YES	YES	YES	NO	NO	NO
Year Fixed Effects	YES	YES	YES	YES	YES	YES

Robust standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

	(1)	(2)	(3)	(4)	(5)	(6)
	wheatprod	pctcropfailure1	pctcropfailure2	wheatprod	pctcropfailure1	pctcropfailure2
>50k AF H2O Presence (Irrigation)	1.3031	-0.0011	-0.0497	1.2587	-0.0023	-0.0523
	(0.6129)**	(0.0034)	(0.0145)***	(0.6360)*	(0.0035)	(0.0165)***
Average Spring - Summer Precipitation	-0.6503	0.0030	0.0091	-0.8700	0.0033	0.0078
	(0.1378)***	(0.0010)***	(0.0027)***	(0.1985)***	(0.0008)***	(0.0023)***
Average Annual Temperature	0.1410	0.0012	0.0074	0.0698	0.0009	0.0040
	(0.1306)	(0.0004)***	(0.0017)***	(0.1045)	(0.0003)***	(0.0012)***
Palmer Drought Severity Index (Avg.)	0.3165	-0.0065	-0.0109	0.4075	-0.0067	-0.0116
	(0.1532)**	(0.0012)***	(0.0018)***	(0.1472)**	(0.0012)***	(0.0020)***
Average Soil Quality	0.6164	0.0005	-0.0112	0.4760	0.0022	-0.0083
	(0.3276)*	(0.0018)	(0.0061)*	(0.3833)	(0.0021)	(0.0072)
Observations	8341	6068	5947	8341	6068	5947
Cluster Fixed Effects	26	26	26	26	26	26
R-squared	0.53	0.49	0.36	0.51	0.48	0.33
State Fixed Effects	YES	YES	YES	NO	NO	NO
Year Fixed Effects	YES	YES	YES	YES	YES	YES

Robust standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 5: Comparison of Dam Size

	(1)	(2)	(3)
	wheatprod	pctcropfailure1	Pctcropfailure2
Irrigation Dam Presence (>50,000)	2.3043	-0.0094	-0.0564
	(0.3453)***	(0.0044)*	(0.0191)**
Irrigation Dam Presence (>40,000)	1.8503	-0.0087	-0.0535
	(0.3088)***	(0.0045)*	(0.0180)**
Irrigation Dam Presence (>30,000)	2.0122	-0.0097	-0.0582
	(0.2604)***	(0.0044)*	(0.0181)**
Irrigation Dam Presence (>20,000)	1.7212	-0.0085	-0.0574
	(0.3589)***	(0.0045)*	(0.0185)**
Irrigation Dam Presence (>10,000)	1.2341	-0.0080	-0.0570
	(0.3989)**	(0.0045)	(0.0174)**
Observations	8341	6068	5947
Number of cohorts	8	8	8

Robust standard errors in parentheses

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