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Analysis

Long-term impacts of major water storage facilities on agriculture and the natural environment: Evidence from Idaho (U.S.)

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ABSTRACT

This paper investigates the long-term impacts of water storage infrastructure (dams) on agriculture and the natural environment in the semi-arid U.S. West. We conduct an empirical analysis of the agricultural impacts associated with major dams in Idaho, focusing on their crop mixes, crop productivities, and overall agricultural land values using an integrated county-level repeated cross section dataset. Our results suggest that the presence of a dam resulted in significant increases in total crop acreage, particularly in those counties in which farmers have predominantly junior water rights. Dams led to an increase in the acreage of the higher-valued, more water-intensive crops and positively impacted some crop productivities, particularly during periods of severe droughts. In contrast to the traditional literature, we find that the presence of a dam had a small, positive, but non-significant effect on farmland values. Finally, we evaluate long-term patterns in stream flow change and examine the impacts of dams on the natural environment. We find that the presence of dams enabled the spatiotemporal transfer of water resources from cold (non-agricultural) to warm (agriculturally-intensive) seasons, reduced the potential availability of water resources for ecosystem use, and increased the seasonal volatility in water supplies.

1. Introduction

Land in the western United States is North America's driest and has its most variable climate (Lettenmaier et al., 2008). Agriculture in this region is particularly vulnerable to variability in water supply, and relies heavily on irrigation (Olmstead and Rhode, 2008).[3] Recent literature on climate change has highlighted the impact that climate change may exert on irrigated agriculture across arid and semi-arid regions in the western U.S., as well as in Australia, the Middle East, and along the Mediterranean Coast, as temperatures and variations in precipitation are predicted to increase (Ragab and Prudhomme, 2002). Consequently, many studies address the impact of climate change on agriculture as well as potential agricultural adaptation responses (including, among others, Adams, 1989; Adams et al., 1990, 1995, 1999; Mendelsohn et al., 1994; Schlenker and Roberts, 2009; Schlenker et al., 2005, 2006, 2007). A number of other studies examine the specific concerns of irrigated agriculture in arid and semi-arid regions, including reduced and more variable water supply, impact of increased salinity due to lower flows, and many other water management issues (for example, Azad and Ancev, 2010; Fleischer et al., 2008; Gómez and Pérez-Blanco, 2012).

Concerns over the variability of water supplies are not new. As population increased and agricultural development expanded in the western U.S., major water infrastructure projects (large dams, reservoirs and canals) were initiated throughout the 20th century. These infrastructure projects helped reduce the variability associated with seasonal water supplies and enabled water managers to meet the historical demand for agricultural irrigation, and provided hydroelectric power, flood protection, and drinking water supplies. However, in addition to their enormous up-front construction costs, the major water storage facilities also brought about a number of environmental concerns, including the problems associated with low flow rates, increased salinity and impacts on native fish populations.

This paper addresses the long-term agro-ecological impacts of water storage infrastructure development in the western U.S. using Idaho as a case study. We examine the agricultural land use and crop productivity benefits of water storage infrastructure during 1920–2002, and address some of the potential ecosystem impacts, such as low levels of stream flow and water supply variability that may have been artificially exacerbated by the water supply infrastructure.

We construct and utilize an integrated, historical, county-level repeated cross section dataset of major water storage infrastructure projects in Idaho, which spans most of the twentieth century. We use this information to investigate the extent to which dams helped to stabilize agricultural production, especially during major droughts and under the

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[3] U.S. Department of Agriculture (USDA) reports that in 2007, of the ~23 million hectares of irrigated cropland and pastureland in the U.S., nearly three-quarters was in the 17 western-most contiguous states and according to USDA's Farm & Ranch Irrigation Survey (FRIS) irrigated agriculture applied 112.5 billion cubic meters of water, with over four-fifths being used in the arid and semi-arid West in 2008 (USDA-ERS, 2007).

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influence of different water rights priorities. Water rights data are consolidated at the county level in order to better address the priority and sources of water resources that are available to agricultural irrigators. By spatially linking the topographic characteristics, historical climate data, historical agricultural data and water rights data, and focusing on historical episodes of severe droughts, we are able to provide a historical case of adaptation, specifically focusing on the impact of water infrastructure. For the agricultural sector, we utilize a difference-in-difference estimation method and empirically analyze the impact of the presence of a dam on changes to crop mixes, productivity, total cropland acreage, and farmland values. In addition, we take advantage of long-term stream flow data and investigate the spatio-temporal transfers of water resources from cold (non-agricultural) to warm (agriculturally-intensive) seasons due to the presence of major water infrastructure.

Our results indicate that the construction of a dam resulted in positive and statistically significant impacts on crop water-use intensity, productivity, and total cropland acreage over time. We observe that both new and existing farms increased their share of higher valued and more water intensive crops when faced with increased water availability. We also observe that the presence of a dam had a generally large, positive productivity effect, and that this effect was particularly strong during those periods with severe droughts, for some, but not all crops in Idaho. In contrast to the traditional literature which posits that infrastructure improvements were important in increasing the value of farmland in the arid and semi-arid West, our results indicate that the presence of a dam has a positive, but non-significant effect on farmland values. In addition to these financial benefits, we find that the construction of major dams in Idaho spatiotemporally transferred water resources between cold and warm seasons, reduced the portion of water resources available to in-stream uses, and increased the seasonal variability in water supplies, thus negatively affecting the natural environment.

2. Impact of Dams on Irrigated Agriculture and the Natural Environment

Historically, major water infrastructure has played a critical role in influencing agricultural production and productivity in the western states. Without storage and distribution infrastructure, agriculture is limited by the capacity that nearby rivers and streams can carry, and by the often uncertain seasonal weather conditions. Prior to the development of dams, agriculture was generally found in those lands in close proximity to riparian areas, or along ditches that were constructed off of the major rivers. The long-distance delivery of water was difficult, and the construction of major water storage facilities was both costly and risky for private farmers. Because of this, land that was located farther away from the riparian areas, although often of a similar or higher quality as the riparian lands, was largely uncultivated (French, 1914; Hibbard, 1924). Limited irrigation resources not only inhibited agricultural production, but also reclamation and settlement on public land across the West. Federal legislation, including the Carey Act (1894) and Reclamation Act (1902), promoted major water storage and distribution infrastructure projects in the western states through federally funded projects that enabled the delivery of water to users at a great distance from the major watercourses.

The increased access to irrigation water, based on the establishment of new water rights, which varied greatly across states and regions in the western U.S., resulted in a number of different outcomes. Existing farms could, on average, receive more water per acre in the form of storage water, which would enable them to grow more water-intensive crops (crop shifts), to use more water for crops that were already in rotation (thus potentially increasing the yield per acre) and to expand their existing cropland acreage. Moreover, access to storage water may have generated distinct short- and long-run impacts as farmers adjusted their crop choices (Hornbeck and Keskin, 2011).

In the long run, farmers would be better able to respond to drought risks with increased access to irrigation water sources. Specifically, access to irrigation decreases the negative impact of the drought, particularly for the farmers that grow more water-intensive crops. This adjustment process may be gradual as the stored water can only be distributed slowly and based on available technology, but the overall value of access to surface water is capitalized quickly into the land values in anticipation of the increases in agricultural rent (Hornbeck and Keskin, 2011). The new farms that benefit from the additional surface water rights that are created as new dams are constructed, are established on lands otherwise not used for farming. This farmland expansion would certainly increase the total acreage in production, but could have an indeterminate effect on the productivity (yield per acre) of the crops that are grown and on the variety of crops that are grown. It is also important to note that the potential impacts of increased access to irrigation water could be strongly moderated by the distribution of the storage water rights. The additional water that is made available through the increased storage capacity will not be equally allocated to every water user, and thus, there will be potentially divergent responses in regions with differing water rights priorities and water supply conditions.

Increased water storage and distribution channels extend agricultural land use and cause many negative environmental impacts in these arid and semi-arid regions. Agricultural production is associated with soil erosion, chemical use and contamination, pollution of ground and surface water, loss of genetic diversity, and pesticide resistance (Soule et al., 1990). Agricultural practices impact a wide range of ecosystem services, including water quantity and quality (lower flow rates and lower water quality due to increased run off of nutrients, sediments and dissolved salts from agricultural lands), soil quality and even air pollution from pesticides, dust, and allergenic pollens (Dale and Polasky, 2007). The Millennium Ecosystem Assessment (2005) found that increases in agricultural production between 1960 and 2000 negatively affected ecosystem services, and led to major declines in wild fish stocks and decreases in the quantity and quality of fresh water.

Irrigation practices and large dams result in a number of additional ecological problems stemming from the diversion and depletion of streams and rivers. These hydrologic alterations may in turn affect fish and other wildlife habitats, and introduce saturation and salinity problems that reduce farmland quality and degrade water quality (Soule et al., 1990). In addition, the stabilization of natural flows can result in the elimination of native fish that need high levels of variation in natural flow rates and in the establishment of invasive fish species (Holling and Meffe, 1996). Thus, as river flows are increasingly regulated in order to support growing populations and their agricultural needs, these benefits "come at unforeseen and unevaluated cumulative ecological costs" (Trush et al., 2000).

In this study, our main objective is to empirically examine the long-run impacts of surface irrigation, focusing specifically on the financial impacts of the large dams on agricultural land use and crop productivity. Since our analysis covers most of the 20th century and it is impossible to quantify all of the negative ecological impacts of the major dams, we use an alternative strategy to better understand the negative impacts that result from reduced stream flows in Idaho. Instead of incorporating ecological costs into our empirical models, we survey these negative impacts and describe the extent of the specific problems that they introduce in Idaho and other arid and semi-arid regions.

3. Historical Background

3.1. Agriculture

Like many western states, access to irrigation water was vital to the success of agriculture, and thus human settlement, in Idaho. Idaho is distinct in that it presents a very broad area of agricultural land, with climatic, hydrologic, topographic and other agriculture-related characteristics that vary considerably from region to region (Brosnan, 1918). Agricultural operations in Idaho are extensively distributed along the Snake River Basin and its major tributaries, where conditions are more

Table 1
Storage and Water Rights in Idaho 1910–2000.

Dam completion year	Storage	# Dams	Agricultural census year	Ratio surface water rights to ground water rights	Mean surface water right vintage
1910–1919	2,173,450	14	1920	179	1900
1920–1929	131,573	6	1930	192	1903
1930–1939	303,378	6	1940	119	1906
1940–1949	1,169,090	10	1950	60	1908
1950–1959	5,874,917	10	1959	20	1911
1960–1969	64,459	8	1969	9	1914
1970–1979	5,500,870	15	1978	6	1917
1980–1989	134,287	11	1987	5	1919
1990–2000	255,707	8	1997	4	1920
Unknown	378,628	10			
Total:	17,590,724	111			

Note: Storage reflects the maximum storage, in AF, behind the dams in the given state.

favorable for farming and grazing. In order to capitalize on the regional advantages created by the natural conditions and existing agricultural development, agriculture in Idaho has become exceptionally diverse; thus, farming methods (humid, irrigated and dry farming), crop mixes and rotation patterns vary substantially across regions.

3.2. Settlement and Development

The historical development of the agricultural landscape in Idaho largely depended on major reclamation and settlement efforts, especially the construction of major irrigation projects. It is evident from Tables 1 and 2 that dams and reservoirs greatly increased the state's water supply capacity and improved agricultural productivity and planted acreage across the state. The development of irrigated agriculture, in turn, promoted the expansion of urban settlement and reclamation across the state. [4]

3.3. Water Governance

Reservoir storage is recognized as one of the chief features of water utilization in the water rights jurisprudence throughout the West (Hutchins, 1977). In general, the establishment of institutions and governance of water rights was encouraged by the federal government, and was often a necessary condition in order to receive federal funding. Thus, the construction of major irrigation facilities contributed to the formation of Idaho's water governance system. Like most other arid and semi-arid western states, the appropriative governance and management of water resources were given substantial attention. The Idaho law of water rights was established in 1893, in which the Wyoming Water Code of 1890 was adopted, with minor revisions (Dunbar, 1983). The current water regime in Idaho was built upon the prior appropriation doctrine, where beneficial use, priority in appropriation, and appurtenance of water right to land are the basic principles recognized in the Idaho code of water rights.[5]

[4] Documents suggest that Mormon settlers first introduced irrigation to the state in 1854 in Lemhi County and the first permanent settlers in the Salmon River Valley of Franklin County practiced farming in 1860 (French, 1914). Most of the Mormon settlers came from the Cache Valley area near the Idaho–Utah border and their settlements quickly extended in to the Upper Snake River Valley (Valora, 1986). With the construction of the Oregon Short Line along the Snake River tributary, settlement and reclamation expanded further westward throughout the southern sections of the state (Brosnan, 1918).

[5] The principle of beneficial use was deeply rooted in the national land policy at a time when most of the land in the West was in the public domain and the allocation of such land was a national priority (Hibbard, 1924; Hutchins, 1977). The Desert Land Act of 1871 clearly declared that the use of water shall depend on bona fide prior appropriation (43 USC § 321), and was designed in order to prevent water from being wasted. The principle of priority use, generally known as "first in time is first in right" between appropriators, is declared in the Idaho constitution, in the appropriation statute, and through decisions of the Idaho Supreme Court (Hutchins, 1977; Idaho Code. Ann. § 42–106; Idaho Const. art. XV § 3). The rule of appurtenance to land is based on the Idaho law of water rights, and resembles a key feature of the 1890 Wyoming Water Code (Dunbar, 1983), which was intended to advance land reclamation and settlement and to discourage land speculation (Hibbard, 1924; Mead, 1903).

4. Data, Conceptual Framework and Empirical Models

In this section, we first present the data and explain how we compile and manage the data set for our empirical analysis. Next, we present the conceptual framework, which differentiates between the agricultural impact model (the empirical model that constitutes the core of this paper) and the environmental statistical analysis that measures the potential impacts that dams have on the environment. Finally, for the empirical agricultural model, we explain the model specification and the hypotheses that we address in this study.

4.1. Data

In order to analyze the impact of dams on agricultural activities and farmland values in Idaho, we have compiled a detailed repeated cross section dataset that consists of dams, ground and surface water right distributions, and historical agricultural productivity, as well as historical climatic and weather conditions and geographic characteristics. Our data are consolidated at the county level and are measured across all 44 Idaho counties, for 18 agricultural census years (1920–2002), with a total number of 792 observations.

Our primary source for the major water infrastructure data is the National Inventory of Dams (NID) by U.S. Army Corps of Engineers. The data include important characteristics for major dams in the U.S., including the location, ownership, year of completion, primary purposes, capacity and height.[6] Based on the primary purposes of construction, we distinguish irrigation dams from dams of all other purposes.[7] The geographic distribution of major irrigation dams in Idaho is presented in Fig. 1. We identify 111 major dams within the state, with a maximum storage capacity of over 21.6 billion cubic meters (BCMs). Dam construction in Idaho thrived in the post-WWII period — with the vast majority of dams constructed during the 1950s, 60s and 70s. This temporal pattern of the water infrastructure development is very similar to those in the other western states (Hansen et al., 2011).

To address the institutional effects of water rights at the regional level, we identify the water delivery area of each irrigation dam and

[6] There are approximately 80,000 dams in the Army Corps of Engineers database, 8121 of which are considered to be "major." Based on our examination of dam characteristics in the Idaho, we do not think that omitted smaller dams were comparable to major dams in providing storage capacity for irrigation. Specifically, 111 major dams in Idaho have a mean maximum storage of over ~191 million cubic meters (MCMs) and a mean height of 35.05 meters. In contrast, 478 smaller dams have a mean maximum storage of only 0.85 MCMs and a mean height of 6.10 meters. Since 2159 cubic meters of water is expected to produce at most ,722 kg of wheat per irrigated acre, a dam of 0.85 MCMs can provide enough water to hydrate only about 158.64 hectares of farmland, producing approximately 1089 metric tons of wheat (Brouwer and Heibloem, 1986).

[7] The primary purposes of construction include flood control, debris control, fish and wildlife protection, hydroelectric generation, irrigation, navigation, fire protection, recreation, water supply enhancement, and tailings control. In our sample, over 40 percent of the dams in Idaho have irrigation listed as the primary purpose and nearly 50 percent of all dams have irrigation listed as one of the essential purposes.

Table 2
Total Acreage and Yield per Acre in Idaho 1920–2002.

Agricultural census year	Value per acre ($1984)	Total cropland (1000 acres)	Total harvested acres (1000 s)					Mean county yield per acre				
			Alfalfa/Hay	Wheat	Barley	Potatoes	Sugarbeets	Alfalfa/hay	Wheat	Barley	Potatoes	Sugarbeets
1920	353	4512	1170	1141	68	43	37	1.73	14.6	18.2	105	7
1925	277	3714	1162	806	117	61	39	1.46	16.8	22.1	122	6
1930	284	4073	1151	1295	133	77	48	1.52	22.9	29.8	143	11
1935	240	3932	1188	879	96	124	33	1.41	23.5	31.4	139	8
1940	241	3929	1121	880	214	125	71	1.83	26.1	32.9	148	14
1945	235	4590	1151	1049	289	164	42	1.91	30.2	38.3	109	14
1950	306	5230	1041	1787	304	145	58	2.04	23.4	31.9	126	15
1954	357	5476	1113	1155	541	150	86	2.26	31.4	34.5	154	16
1959	423	5784	1162	1087	500	200	91	2.25	36.0	35.2	170	20
1964	422	5878	1328	1041	464	228	170	2.37	38.5	44.0	162	15
1969	468	6172	1180	961	659	272	171	2.65	41.7	51.8	189	17
1974	669	6248	1323	1414	725	316	207	2.61	40.5	45.3	203	17
1978	955	6540	1322	1362	986	362	128	2.75	51.8	61.2	248	20
1982	889	6264	1223	1507	1090	319	137	2.85	57.8	65.5	273	23
1987	554	5975	1173	1239	832	352	168	2.69	63.2	68.5	288	26
1992	569	4822	1063	1385	691	371	199	2.84	64.5	66.1	314	24
1997	745	5794	1260	1411	711	386	193	3.13	74.6	74.9	337	28
2002	823	6153	1285	1201	634	357	201	3.08	69.1	74.7	351	25

Note: Yields: wheat, barley and corn in bushels/acre; potatoes in cwt/acre; sugarbeets and alfalfa/hay in tons/acre.
Storage reflects the maximum storage, in AF, behind the dams in the given state.

spatially link our water infrastructure data with the county-level agricultural census data. Specifically, we identify the water delivery area of every irrigation water storage project, which delivers water subject to the *place-of-use* requirement of individual water rights under the prior appropriation doctrine. The water delivery areas of individual dams were determined by surveying the operators or management agencies for each of the major dams in Idaho.[8] Thus, if a county is located within the water delivery boundaries of any dam, it is assigned access to the supply of irrigation water (measured in both volume of water and the number of irrigation dams) for all subsequent years after the completion of that specific dam. This survey provides a more accurate representation of the spatial distribution of water from major dams, even though it does not address any temporal changes in the annual amount of water supplied from major dams.

In order to correctly address the impact of dams on agricultural productivity and farmland values, it is important to account for the water right institutions and regional advantages in water use. Due to the regional differences in the history of reclamation, settlement, and irrigation project construction, the availability of irrigation water and the competition for the water resources vary significantly across regions. Although we have access to very detailed data on water infrastructure, historical irrigation water access data is much more difficult to obtain. Therefore, we approximate access to irrigation water supply by taking into account those factors that are relevant to water right institutions at the regional (i.e. county) level.

To control for this inter-region priority in water appropriation, we utilize the water rights geospatial data from the Idaho Department of Water Resources (IDWR). First, we identify the county-level mean surface water priority date by using the priority dates of individual water rights that have already been established before each agricultural census, within each county. Next, we calculate the ratio of the number of surface water rights to ground water rights for each county in each agricultural census year, and summarize the descriptive statistics in Table 1. We introduce the water rights ratio directly into our models, and use the water rights priority measure to construct an indicator variable for the top 25 percent of counties in each census year, in terms of seniority. We interact this indicator variable with an indicator that equals one if the county is dominated by surface water rights in any give year (>10:1 ratio). In this way we are able to directly account for those counties that have large surface water rights holdings, as well as those counties that have more seniority in the water priority hierarchy.

Historical agricultural data for each census year from 1920 through 2002 are compiled by the U.S. Census of Agriculture.[9] We use the total planted acreage, total harvested acreage by crop (measured in tons or bushels per acre), and average farmland values to measure crop composition and agricultural productivity. We have collected data for the major crops in Idaho, including potatoes, sugarbeets, wheat, barley and hay. We should note that the measures and definitions of agricultural data may change over time. For example, in the early years of the agricultural census, certain forage crops were listed as a single entry, but in later years the forage crops were split into multiple categories. In the models in which we are interested in individual crops that have been further divided into sub-crops, we aggregate so that the unit of measure is consistent across all of the years of our sample.

Historical climate data are collected from the U.S. Climate Division Dataset (USCDD), which provides averaged annual climate data based on 344 climatic zones, covering 1895 to present. The USCDD include various temperature and precipitation measures, including the monthly maximum, minimum, mean temperatures, total monthly precipitation levels and the Palmer Drought Z-Index. We use the Z-Index measure as a proxy for "moderate to severe droughts." The Z-Index uses temperature and rainfall information in a formula to determine relative wetness or dryness, and is most effective in determining long-term droughts—a matter of several months. Additionally, we examine persistent impacts of droughts by using the two-year lagged values of the Z-Index in our robustness checks.

The long-term stream flow data are provided by the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS).[10] The

[8] A questionnaire was administered via telephone to all major dam operators in Idaho. The information collected through these questionnaires includes whether water is withdrawn onsite, downstream or both, the counties (and the acreages) that dams supply irrigation water, and primary method of withdrawing water (pump or canals). We were able to collect data on the total number of wells providing water to agriculture, but the data is measured in 2009 and therefore doesn't reflect the changing availability of well water over time, nor does it represent the volume of well water available. We acknowledge that the availability of well water and the electrification of the farm increased the agricultural potential in many counties in Idaho.

[9] The early years of the agricultural census were conducted decennially, until 1920, after which the data was collected every five years. In 1954 the census was modified such that it was still conducted every five years, but only during those years ending with a 4 or a 9. In 1978 the agricultural census was conducted, and then modified again such that it was conducted every five years, but only during those years ending with a 2 or a 7.

[10] For the stream flow statistics, the water year starts in October and ends in September of the subsequent calendar year. The majority of the stream flow measurements in Idaho do not cover a long time horizon. Using the stream flow data in empirical models will necessitate the removal of a substantial number of observations. Therefore, stream flow data are not used in our regression analysis.

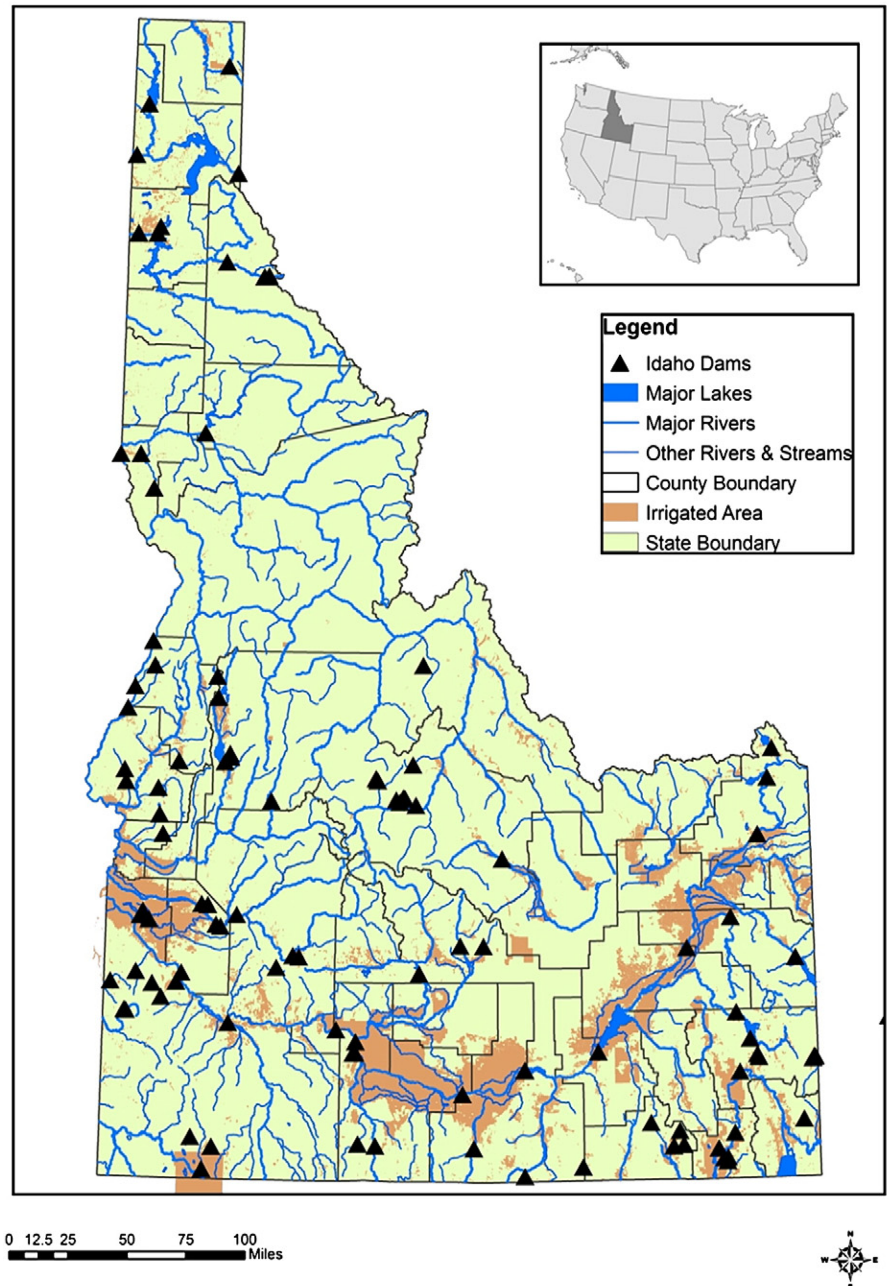

Fig. 1. Spatial Distribution of Irrigation Dams in Idaho.

data provides monthly, adjusted total amount of streamflow and the reservoir storage (or carryover) for the major and minor streams in Idaho (USDA NRCS 2012). The adjusted stream flow (i.e. "natural flow") represents the total available water supply under an uninterrupted scenario in which the carryover from dams and reservoirs is included. We calculate the annual, warm-season (April–September) and cold season (October–March) adjusted streamflows by summing up their respective monthly values. We also calculate the observed streamflows by subtracting the corresponding upstream reservoir change-in-storage volumes from the adjusted stream flow volumes.[11] Compared to the observed streamflow measurement, the uninterrupted or unimpounded "natural flow" condition is an artificial, counterfactual construct, which better indicates the total amount of water available before irrigation diversions are made. The observed flow, on the other hand, better reflects the outcomes under the contemporary water governance systems in Idaho, after water is made available to irrigation enterprises and the natural environment.[12]

[11] For the stream flow statistics, the water year starts in October and ends in September of the subsequent calendar year. The majority of the stream flow measurements in Idaho do not cover a long time horizon. Using the stream flow data in empirical models will necessitate the removal of a substantial number of observations. Therefore, stream flow data are not used in our regression analysis.

[12] The change-in-storage measurements are calculated by taking the differences in reservoir storage levels between the ending and starting months. For the annual measurement, the ending month is September and the starting month is October of the previous calendar year. For the warm-season measurement, the ending month is September and the starting month is April. For the cold-season measurement, the ending month is March and the starting month is October of the previous calendar year. We note that the differences in the March and April values may contribute marginally to the differences in the mean annual measurements between the observed and adjusted streamflows.

4.2. Conceptual Framework

Historically, Idaho has been an agriculture-dominated state with a vast agricultural demand for water. [13] The natural and agricultural environment is critically dependent on water, especially in arid and semi-arid regions like Idaho. Therefore, we consider a simple conceptual framework where the impacts of major dams can be partitioned into two sectors: agriculture and the natural environment.

To motivate our analysis, 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:

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

The water supply related factors include the indicator of major dams and their service areas, the water right priority measure and 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, and droughts. Using this conceptual framework and utilizing empirical analyses, we seek to address the following research questions:

1. By how much did the total cropland acreage increase in a county following the construction of a major dam?
2. What was the impact of a major dam on agricultural productivity (harvest/acre) and crop mix?
3. What was the impact of a major dam on farmland values?

For the natural environment, we posit that the goods and services natural environment provides (E) are a function of water supply-related factors (W') and other features of the natural environment (X'). That is:

$$E_{it} = H\left(W'_{it}, X'_{it}\right) \tag{2}$$

Unlike the more detailed records of agricultural and climatic data, the long-term record of ecological conditions and the changes in these conditions are generally unavailable at the county level. Therefore, we utilize a different strategy to analyze the impacts of major dams on the natural environment. Instead of using a regression analysis to examine the impacts of dams on ecosystems, we describe the changes in water that is supplied to the natural environment over time (total water supply net of the portion for agricultural use). Utilizing data on the long-term total water supply, we exploit the spatio-temporal patterns of water transfers between cold and warm seasons and analyze their impacts on the natural environment with respect to the level and volatility of water supplies for both agriculture and in-stream uses.

4.3. Empirical Models of Agricultural Impacts

To evaluate the role that major water infrastructure has played in altering agricultural composition and productivity levels, we specify models to estimate the impact of major water infrastructure on cropping mixes (the share of different crops), crop outcomes (yield per acre), and farmland values, using the data sources outlined previously. We hypothesize that, *ceteris paribus*, following the completion of a major water storage project in the relevant county: 1) the productivity (yield/acre) would increase; 2) the portion of water intensive (and more valued) crops (as a share of the total crop mix) would increase; 3) the total cropland could increase, especially in counties where there is a larger share of farms with junior rights to surface water; and 4) the total revenue and farm land values would increase if the new water supplies are allocated to existing farms (due to the expected increase in the per-acre yields). However, if the new water supplies are allocated to new farms on marginal lands, we may observe per-acre yields that are similar to, or even below, those of the existing water users with senior rights to surface water, and thus the mean value of the farmland may actually decrease.

We let H_{it} denote the agricultural outcome in county i, in year t. We allow H_{it} reflecting a series of different measures: 1) the percentage of land dedicated to each major crop (thus reflecting changes in composition); 2) the yield per acre for each major crop; and 3) farm land values, before and after a major water infrastructure project is completed.[14] D_{it} is an indicator variable that equals one when county i has access to irrigation water provided via a major water infrastructure project in year t, and zero otherwise.[15] Our basic econometric model is Eq. (3) below:

$$H_{it} = \alpha D_{it} + BI_{it} + \phi X_{it} + \theta_t + \eta_{it} \tag{3}$$

where α measures the difference in the dependent variable within counties *with and without* major water infrastructure projects.[16] I_{it} represents the occurrence of a particularly dry period, using the Z-Index. X_{it} is a vector of controls that vary over time at the county level, and includes the annual precipitation and temperature measures, as well as the water right type ratio and the measure of water right priority.[17] θ_t is a year fixed effect, and η_{it} is the unobserved error component.

To further test whether the major water infrastructure provides security during times of drought, we utilize a difference-in-difference (DID) model, presented in Eq. (4) below, where we interact D_{it} with the indicator variables for those periods in which agriculture experienced a particularly dry period (I_{it}): [18]

$$H_{it} = \alpha D_{it} + \beta I_{it} + \gamma[D_{it} * I_{it}] + \phi X_{it} + \theta_t + \eta_{it} \tag{4}$$

Using the DID model, we are able to differentiate the impact of dams on agricultural productivity and on crop mixes during moderate to severe drought periods relative to periods with "normal" climatic conditions. For example, we expect to see that γ is positive and statistically significant in models where the dependent variable measures crop productivity.

We should note that when some counties' natural advantages are overlooked, this empirical exercise could suffer from spurious positive correlation and thus generate bias for traditional OLS approaches. For example, reservoirs are more easily built in mountainous areas than on the plains. If such advantage is present in one county, farmers in that region should expect to see larger productivity gains from an increased volume of irrigation water, and may be more likely to invest in a major water infrastructure project. To overcome this specification issue and to control for differing water rights across regions, we estimate our models using county fixed effects. Identification therefore comes from the within-county differences in the availability of irrigation water over time, and county specific characteristics (for example,

[13] 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 (Solley et al., 1988a,b; Hutson et al., 2004; Kenny et al., 2009).

[14] It is worth noting that in most cases, the dependent variable (harvest per acre or the composition of different crops produced) is not biased by the size of the county. In models in which the total land area of the county may affect our results, we normalize by the total land area of the county.

[15] We begin with a 61.67 MCMs cutoff to construct the indicator variable for irrigation water provided by dams, but relax this cutoff as a robustness check. As expected, as the cutoff level decreases, so does the magnitude of the coefficient on the dam indicator variable.

[16] We construct the dam indicator as a binary variable so that it represents only those projects with a dedicated purpose of irrigation. In these cases, dams that were constructed for hydroelectric, recreation or other purposes without any indication that they will provide irrigation water are not included as dams in our analysis of agricultural impacts.

[17] In order to account for non-linearity in the precipitation and temperature variables, we include square measures of both in all of our models.

[18] Difference-in difference (DID) model is a technique that helps measure the effect of a treatment at a given period over time. The DID estimator measures the difference in an outcome before and after treatment (within subjects treatment effect) as well as the differences of the treatment and control groups (between subjects treatment effect). See Wooldridge (2010) for a more detailed theoretical discussion of the DID methodology, or Ashenfelter and Card (1985) for an early application.

Table 3
OLS Fixed Effects Models of Crop Coverage.

	(1) % Hay	(2) % Wheat	(3) % Barley	(4) % Potatoes	(5) % Sugarbeets	(6) Total Cropland
Irrigation dam indicator variable	−0.6797	0.6028	−1.7524	2.3945	−0.6686	47.1474
	(2.8173)	(1.8196)	(3.6872)	(1.1149)**	(0.5359)	(23.3334)**
Annual precipitation average	−2.8261	−0.6124	2.4121	1.0474	−1.1774	−34.6107
	(5.4905)	(4.8903)	(3.8925)	(2.0908)	(2.9661)	(27.6672)
Annual precipitation average squared	0.8686	0.0449	−0.4614	−0.6837	1.2182	1.8493
	(1.1434)	(0.9138)	(0.8155)	(0.5047)	(0.7883)	(5.3733)
Annual temperature average	0.8870	−2.8234	1.1414	0.3160	4.0675	−19.6100
	(2.8303)	(2.1065)	(1.4916)	(0.9506)	(1.8895)**	(24.7346)
Annual temperature average squared	−0.0172	0.0338	−0.0269	−0.0033	−0.0499	0.1709
	(0.0279)	(0.0201)	(0.0172)	(0.0100)	(0.0203)**	(0.2403)
Severe drought indicator variable	−0.1501	−1.4758	−0.8129	0.6496	−0.9883	−13.6646
	(1.1913)	(0.9149)	(1.4373)	(0.9024)	(0.9079)	(7.6210)*
Severe drought–irrigation dam interaction effect	−2.2258	−0.0301	−0.1141	−1.4141	0.4010	−11.2770
	(2.0580)	(1.3109)	(1.6727)	(1.2009)	(0.6777)	(17.4875)
Water right priority	−4.7418	4.1838	−4.0288	−1.7125	0.5296	−17.5907
	(2.4856)*	(2.2783)*	(1.8007)**	(0.9663)*	(0.7209)	(12.9855)
Surface/ground water ratio	0.0002	0.0025	0.0007	−0.0004	0.0033	0.0091
	(0.0023)	(0.0025)	(0.0041)	(0.0011)	(0.0061)	(0.0130)
Observations	741	712	719	624	320	761
R-squared	0.42	0.23	0.43	0.30	0.38	0.26

Robust standard errors in parentheses.
* Significant at 10%; ** significant at 5%; *** significant at 1%.
Notes: All models include Intercept, Census Year Dummy Variables, Year Time Trend variable, and County Fixed Effects. Total Cropland normalized by total county area.

topography classification and soil type) remain constant. Therefore, we estimate Eq. (4) and present the results in Tables 3 and 4. All of the models that we present include county fixed effects, as well as census year dummy variables and a yearly time trend.

5. Results and Discussion

5.1. Dams and Irrigated Agriculture

Table 3 presents the impact of dams on agricultural composition — shares of total cropland dedicated to the five major crops grown in Idaho, as well as on the total cropland planted. As discussed previously, we expect that those counties that received additional storage water once a dam was constructed were better able to deal with the problems of short-term climatic variability. In our sample counties, the presence of a dam has a *negative* (although insignificant) impact on the acreage dedicated to drought-tolerant crops such as hay and barley, and a *positive* and statistically significant impact on the acreage of water-intensive crops such as potatoes. This suggests that the presence of a dam would likely lead to a change of land use from drought-tolerant lower-valued crops towards water-intensive higher-valued crops. We should also note that the reduction in the composition of hay could be a consequence of both the presence of a newly constructed dam and the increased use of the reclaimed lands, the latter of which was promoted through the added irrigation storage facilities. During the course of reclamation and settlement, it was common for lands to be gradually prepared to grow other crops, the process of which could result in a reduction in the total acreage of hay.

Table 4
OLS Fixed Effects Models of Crop Productivity and Farm Value Per Acre.

	(1) Hay	(2) Wheat	(3) Barley	(4) Potatoes	(5) Sugarbeets	(6) Farm value
Irrigation dam indicator variable	0.2413	−3.0054	−0.2319	8.9665	1.6267	25.2768
	(0.1271)*	(2.8216)	(2.3380)	(8.5390)	(0.9622)*	(39.4512)
Annual precipitation average	−0.0731	−15.0516	12.9856	−40.7142	2.8044	43.4493
	(0.2696)	(9.4793)	(7.3745)*	(57.9496)	(4.3856)	(152.5977)
Annual precipitation average squared	0.0653	3.2408	−2.6132	1.9394	−1.3820	−28.6692
	(0.0652)	(2.0832)	(1.3676)*	(13.8510)	(1.1028)	(38.4447)
Annual temperature average	0.1743	2.0494	2.9448	−47.8200	1.6944	280.0743
	(0.2113)	(3.5263)	(3.1335)	(34.4499)	(1.4022)	(113.0504)**
Annual temperature average squared	−0.0017	−0.0197	−0.0231	0.5395	−0.0200	−3.0114
	(0.0022)	(0.0393)	(0.0353)	(0.3488)	(0.0143)	(1.1624)**
Severe drought indicator variable	−0.1980	2.4803	6.8932	8.8218	2.0174	−60.9197
	(0.1921)	(5.4984)	(4.1563)	(23.8660)	(2.2662)	(70.1837)
Severe drought–irrigation dam interaction effect	0.2043	9.0731	7.9936	7.4803	0.1164	−47.4234
	(0.1830)	(6.0687)	(4.5466)*	(10.8165)	(1.9630)	(70.5460)
Water right priority	−0.0221	5.4346	1.7729	10.4446	0.7051	29.1678
	(0.0854)	(2.1127)**	(1.9412)	(9.6854)	(0.7485)	(22.3003)
Surface/ground water ratio	0.0001	0.0084	0.0049	0.0277	−0.0013	0.0838
	(0.0001)	(0.0050)*	(0.0020)**	(0.0115)**	(0.0057)	(0.0765)
Observations	753	732	738	642	334	632
R-squared	0.71	0.79	0.82	0.65	0.82	0.71

Notes: All models include Intercept, Census Year Dummy Variables, Year Time Trend Variables, and County Fixed Effects.
Robust standard errors in parentheses.
* Significant at 10%.
** Significant at 5%.

Table 5
Historical Patterns of Long-Term Streamflow: Uninterrupted Versus Observed.

	Data year range	Flow measure	Annual		Warm season (Apr–Sept)		Cold season (Oct–Mar)	
			Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
Major Rivers (water storage facilities)								
Snake River at Heise	1911–2008	Uninterrupted	6.25	1.63	4.78	1.50	1.47	0.23
(Jackson Lake and Palisades Reservoir)		Observed	6.20	1.20	4.87	0.76	1.33	0.59
Snake River at Neeley	1927–2008	Uninterrupted	6.46	2.24	3.56	1.94	2.89	0.51
(Jackson Lake, Palisades Reservoir, Grassy Lake, American Falls Reservoir, Island Park Reservoir, and Henrys Lake Reservoir)		Observed	6.43	2.04	4.89	1.11	1.54	1.16
Boise River at Boise	1955–2008	Uninterrupted	2.45	0.99	1.82	0.78	0.63	0.24
(Lucky Peak Reservoir, Arrowrock Reservoir, and Anderson Ranch Reservoir)		Observed	2.36	1.14	2.12	0.56	0.43	0.37
Minor Rivers (water storage facilities)								
Big Lost River	1926–2008	Uninterrupted	0.28	0.10	0.20	0.09	0.09	0.02
(Mackay Reservoir)		Observed	0.29	0.10	0.23	0.09	0.06	0.03
Big Wood River	1917–2008	Uninterrupted	0.43	0.29	0.35	0.26	0.09	0.06
(Magic Reservoir)		Observed	0.49	0.29	0.45	0.25	0.04	0.06
Bear River	1927–2008	Uninterrupted	0.39	0.28	0.28	0.24	0.11	0.06
(Bear Lake)		Observed	0.44	0.41	0.32	0.38	0.12	0.11
Payette River	1920–2008	Uninterrupted	1.84	0.67	1.08	0.39	0.76	0.28
(Cascade Reservoir and Deadwood Reservoir)		Observed	1.88	0.60	1.14	0.32	0.74	0.34
Spokane River	1914–2008	Uninterrupted	5.49	1.93	3.20	1.24	2.30	1.07
(Coeur d'Alene Lake)		Observed	5.52	1.97	3.26	1.32	2.26	1.03

Notes: Streamflow measures are in Billion Cubic Meters (BCMs). The streamflow data do not include evaporation, transfer loss, or return flow. The rivers presented in this table represent a sample of those in Idaho that include some storage capacity along their lengths. Those rivers that lack adjustment or longterm data on streamflow are not presented here.

According to our results, the presence of a dam significantly increased the acreage dedicated to the more water-intensive crops (potatoes) while only marginally reducing the acreage of the more drought-tolerant crops. Thus, we expect to see significant expansions of farmlands. In order to test this hypothesis, model (6) regresses the total cropland (normalized by the size of the county), on the same covariates that were used in models (1) through (5). Our results indicate that the presence of a dam had a large, positive impact on the total cropland in a county. This result suggest that the construction of dams and the subsequent availability of storage water did indeed increase cropland and agricultural production, and that this increase in crop acreage was reflected in the more highly valued and water intensive crop, potatoes. Additionally, our results indicate that the increase in crop acreage came from farmers who held junior surface water rights. In fact, the observed increase in acreage for most crops (except for wheat, which is grown in rotation with potatoes in addition to being a primary crop) came from those counties in which a majority of the surface water rights belonged to farmers with junior priority. Nevertheless, we should note that this result does not preclude the possibility that most of the added storage capacity was dedicated to growing more water-intensive crops on existing farmlands. The positive changes in the productivities of most crops, by contrast, were located in those areas where a majority of the surface water rights belonged to the more senior water rights owners.[19]

Table 4 presents the results of our agricultural productivity models. In these models we see a positive impact of the presence of a dam for two of the crops — hay and sugarbeets. We have already shown that the presence of a dam has a significant impact on the total acreage of cropland, especially on the farms with junior surface water rights. Here, we show that the counties with the more senior surface water rights generally have a positive agricultural productivity outcome (although this is only significant for wheat) relative to those counties with the more junior surface water rights.

We anticipate that the presence of a dam will have a large, positive productivity effect when a severe drought condition occurs and the risk of water shortage is high. We see this positive effect for all of the crops, although it is only significant for barley — resulting in an 18.4% increase in productivity (or ~429.87 kg/hectare). These effects also are economically significant. With an average of ~2,340 kg/hectare, and an average 2013 commodity price of \$0.29/kg for barley, the total per-county revenue from barley is \$3.2 M per year.

Finally, we are interested in the impact that the presence of a dam had on per acre farmland values. When the new water supplies are allocated to *existing* farms with senior surface water rights, as the per acre yields of some crops increase, the mean value of the farmland is expected to increase. However, when the new water supplies are allocated to *new* farms on marginal lands with junior surface water rights, we expect the per acre yields to be below those of the existing (senior) water users, and thus the mean value of the farmland to decrease.[20] The possibility of the latter depends on the quality of the lands that are made arable after the water becomes available. One could imagine a scenario (as was hypothesized with the proliferation of groundwater availability) in which the presence of a dam enables lands to be brought into rotation that are of a *higher* quality than the existing lands. *A priori*, the expected sign of this coefficient is indeterminate.

In order to test these possibilities, we estimate a similar model to those that were presented as models (1) through (5), but we add controls for the composition of the five major crops, and we normalize the total value per acre using 1984 as the base year. Surprisingly, we find that the presence of a dam had a positive but non-significant effect on the value of farm-land as shown in model (6). In this model, the climatic variables, year trends, and the presence of certain crops were more relevant, and explain roughly 71% of the variation in farmland values. It appears that the added storage water may not have benefited every farmer under the prior appropriation doctrine. This result stands in stark contrast to traditional development models that present a connection between agricultural improvements and the value of farmland in the arid and semi-arid West.

It is possible that the development of marginal land may have contributed to this outcome. With the increased construction of water storage faculties, more marginal lands are developed. These lands may have lower returns, which in turn reduce the average productivity per acre

[19] It is also 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 irrigation water supply. This evolution enabled irrigated agriculture on lands with high quality soils but that lacked the necessary access to irrigation water. As a result, the farms that were more dependent on groundwater supplies became less impacted by year to year climatic variability, and thus began to grow higher valued crops on a more regular basis (Xu and Lowe, 2012).

[20] Similarly, it is possible that some of the storage water made available via the dam is allocated to non-irrigation uses (urban, hydroelectric, or other); thus, we would expect the presence of the dam to have an insignificant effect on farmland values.

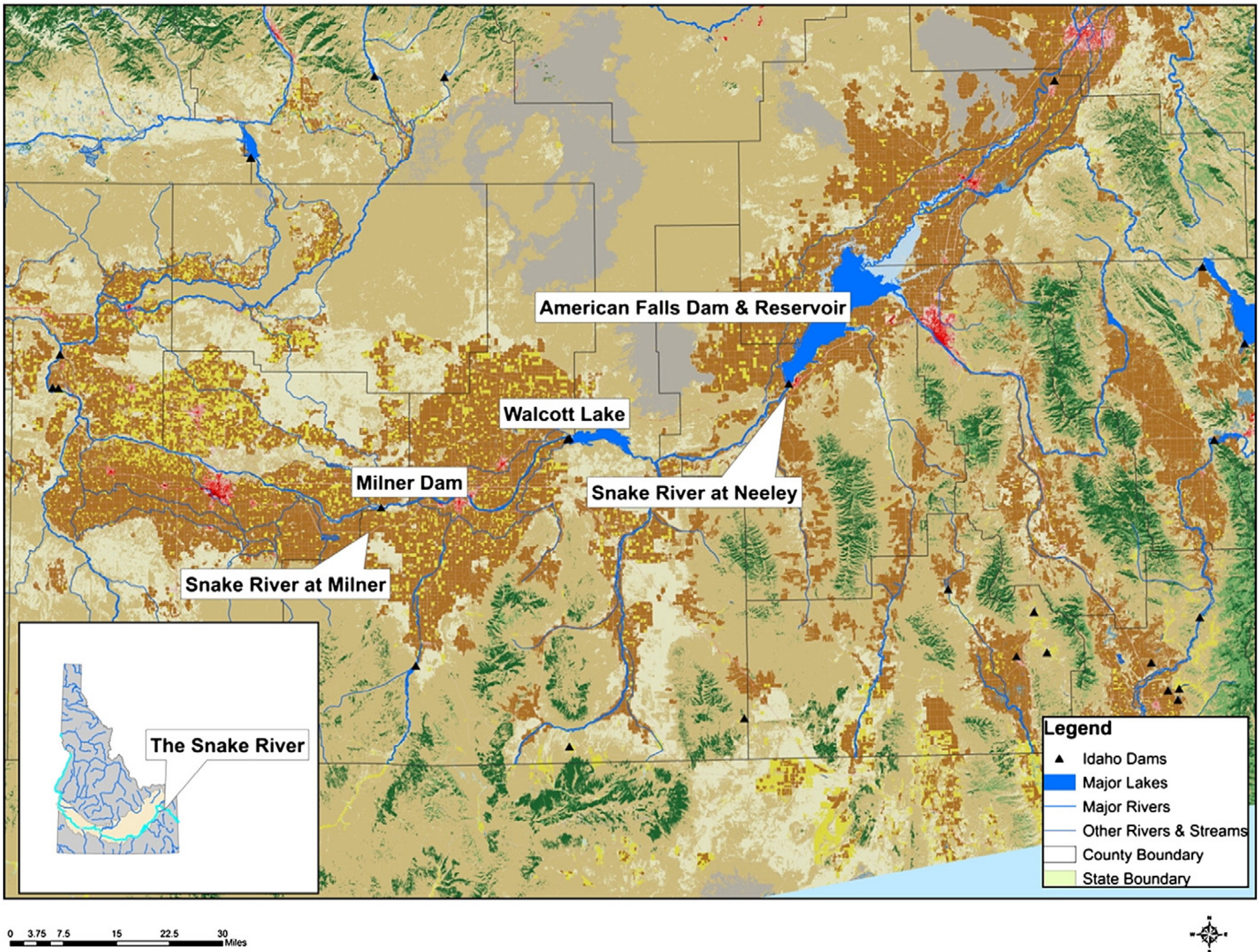

Fig. 2. Snake River at Neeley and Milner.

per farm and eventually lead to decreases in the long-run average farmland value. Moreover, when a water shortage is imminent; the irrigators with newly established water rights face a higher risk of curtailment, and thus larger crop losses than those irrigators with the more senior water rights. As a result, irrigators with newly established water rights may have to devote a larger portion of their land to drought-tolerant and less valuable crops, thus decreasing the average productivity and average farmland values.[21]

We postulate that it is possible that cropping decisions and the resulting productivities per acre are less influenced by current-year or single-year droughts. As a robustness check we run the same cohort of models as were conducted in Tables 3 and 4, but with a two-year lagged average of the Palmer drought Z Index.[22] In general the results are consistent with our expectations. A longer severe drought tends to have an overall negative impact on cropping patterns, and an aggregate negative (albeit insignificant) impact on total cropland. The presence of a dam does little to offset the negative cropping impact of a drought, with the lone exception of barley, for which the presence of a dam has a positive effect on productivity during a prolonged drought period. This leads us to speculate that this non-significance is largely attributable to both a transition of water intensive, high-valued crops to the land with a more stable (groundwater) supply, and a lagged response to newly developed irrigation projects under the prior appropriation doctrine.

5.2. Dams and the Natural Environment

As discussed earlier, dams likely result in negative impacts on the natural environment. In order to address this possibility, we calculate the stream flow patterns with and without major dams for both major and minor streams across Idaho. The descriptive statistics are presented in Table 5.[23] We demonstrate problems associated with low stream flow by carefully analyzing two reaches of the Snake River Basin: Neeley and Milner (Fig. 2).

The Snake River at Neeley is located downstream from the American Falls Dam, which delivers agricultural water across a large geographic area. Historically, the observed average total stream flow (volume) of the Snake River at Neeley is ~6.4 BCMs annually and ~4.9 BCMs during the April–September growing season, measured across the 1927–2008 water years (USDA NRCS 2012). In comparison, the expected "natural flow" (i.e. the adjusted or uninterrupted flow that is calculated by subtracting the reservoir change in storage) is estimated to be

[21] The investigation into the development of marginal land and water rights requires micro-level data over a long time horizon, which currently isn't available. Future data collection will make this analysis possible, and we will address this issue at that time.

[22] The results of these robustness checks are provided in Tables E1 and E2 in the electronic supplementary materials.

[23] As in our conceptual models, stream flows during the warm seasons are used primarily for agriculture, and stream flows during the cold seasons are available for the natural environment (that is, total water supply net of the portion for agricultural use).

~6.5 BCMs annually and ~3.6 BCMs during the April–September growing season, again measured across the 1927–2008 water years (USDA NRCS 2012).

As Fig. 3 illustrates, both the observed stream flow and the "natural flow" conditions display similar patterns over time, with the observed stream flow having a more narrow range of variation. This is particularly true for the observed stream flow during the warm season (April–September) in which it manifests a much higher volume and narrower range of variation. In contrast, the observed stream flow during the cold season is more volatile, with lower volumes. The dramatic differences in the seasonal features of stream flow reveal the role of dams in transferring water and stabilizing water supply, primarily for the purpose of irrigation. The distance between the red and blue lines in Fig. 3 reflects the volume of stream flow that is transferred between seasons, with more water being transferred during the more persistent drought periods (the 1971, 1988–1991, and 2000–2005 drought years).

Along those river reaches in which there are no dams or reservoirs, water flows are appropriated under the governance of a complicated water rights system. Unlike the natural flow rights, when a water right is delivered from a stored location, it stays in the storage facility until it is released, and it is often released to irrigation water rights holders that are located at a great distance from the reservoir or dam itself (for example, the irrigators in the Minidoka-Twin Falls region own rights to irrigation water stored in Jackson Lake Reservoir in Wyoming). These storage rights aren't subject to the same appropriative restrictions that the traditional flow rights are. The spatio-temporal transfer of water resources generates two (opposite) effects: more water is present during the warm season with a lower level of variation, and less water is present during the cold season with higher level of variation. For example, during the 1927–2008 water years, the average observed stream flow in the cold season ranged from ~2.9 BCMs to ~1.5 BCMs, whereas the average observed stream flow in the warm season ranged from ~4.9 BCMs to ~3.6 BCMs; the standard deviation of the observed stream flow in the cold season ranged from ~0.5 BCMs to ~1.2 BCMs, whereas the standard deviation of the observed stream flow in the warm season ranged from ~1.1 BCMs to ~1.9 BCMs.

As shown in the case above, the development of irrigated agriculture in Idaho has resulted in negative implications for the goods and services provided by the natural environment. The presence of water infrastructure has resulted in lower flow rates accompanied with higher levels of variation. This is particularly true when water is shifted between the warm and cold seasons. As many studies suggest (for example, Arthington and Zalucki, 1998; IUCN, 2000; King and Louw, 1998; Postel and Carpenter, 1997; Trush et al., 2000), low stream flow levels with high levels of variation could severely impact ecosystem services and even endanger the natural riparian habitat that thrives in this area. The direct evidence of this is in the flow rates that are observed where the streams leave the major agricultural areas. The Snake River at Milner, located downstream from Milner Lake, is one such area. The discharge of the Snake River at Milner is measured at ~95 cubic meters per second, or ~3.0 BCMs per year during the 1971–2009 water years. In many low-water years, the Snake River below Milner Lake was

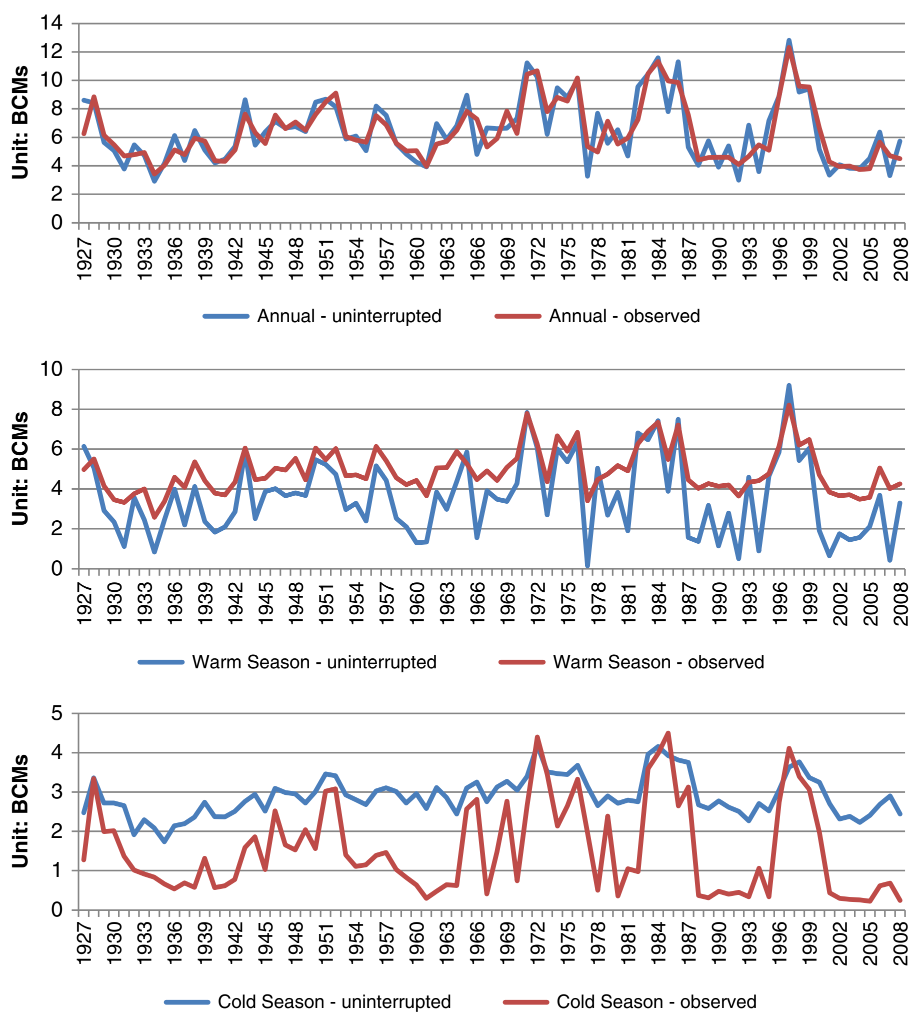

Fig. 3. Time Series of Annual and Seasonal Streamflows along the Snake River at Neeley (Uninterrupted versus Observed).

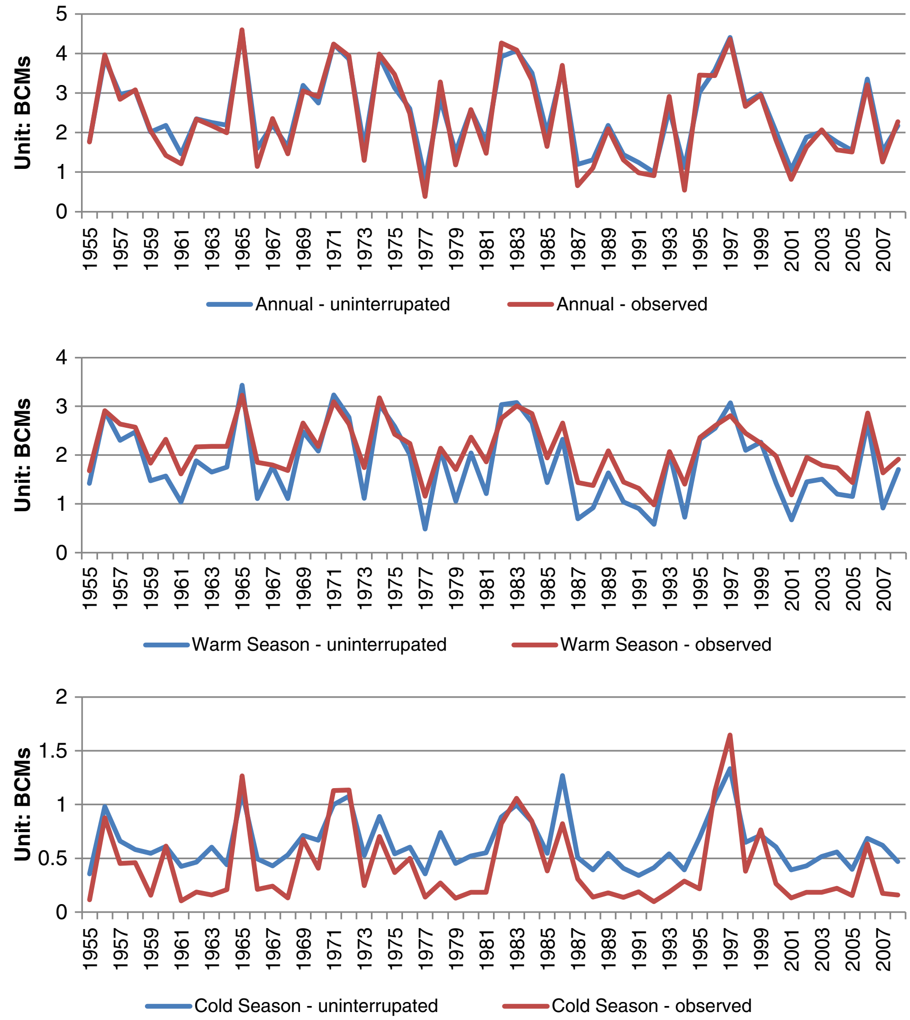

Fig. 4. Time Series of Annual and Seasonal Streamflows along the Boise River at Boise (Uninterrupted versus Observed).

completely diverted to agricultural interests, leaving the riparian area with little more than a trickle of water that had detrimental effects on Snake River salmon, whereas the reservoir storage at the nearby American Falls remained at the same level during these drought periods.[24] Previous studies looked at policy tools such as the management of instream flows and water banking in order to restore the habitat for endangered Snake River salmon, and put the economic costs at $246–359 million per year (Green and O'Connor, 2001; Huppert, 1999).

6. Conclusions

The National Park Service estimates that since the latter half of the 19th century, over 75,000 large water storage projects have modified at least 966 thousand kilometers (17%) of American rivers (NPS, 2013). As the debates regarding dam removals are heated, and the desire to return rivers to their natural flow regimes grows for some rivers, having a better understanding of the benefits and negative impacts that water storage projects provide to society is essential.[25] While the literature is rich with hedonic analyses of water infrastructure projects on property values, recreational use values, and estimates of the value of the hydroelectric power that they provide, very little has been done to measure the agricultural benefits and potential impacts on ecosystems of irrigation-focused water storage projects. In part, this gap in the literature is due to the complexity involved with correctly accounting for the institutional and behavioral responses to the historical water projects, particularly by the agricultural irrigators (Libecap, 2011). The lack of long-term data on the goods and services provided by the natural environment is also to blame. Therefore, a simple comparative analysis (of crop mixes, yields, coverage or farmland values) is unable to capture the true impacts of the water storage project. An analysis such as this requires a more rigorous econometric analysis as well as longer time frame, which this paper provides.

To the best of our knowledge, this is the first longitudinal analysis of the impacts of water storage infrastructure on agricultural outputs and the natural environment. We empirically analyze the long-term impacts

[24] Similar situations to those below Milner Lake are also found in, for example, the Hells Canyon Complex, near the Boise River Basin. The stream flow is measured at the Boise River near Boise, presented in Fig. 4., with three separate upstream dams, including the Arrowrock Dam, the Anderson Ranch Dam, and the Lucky Peak Reservoir. The spatial and temporal transfers of water during the 1955–2008 water years resulted in warm season flow increases from 1.82 BCMs to 2.12 BCMs, and cold season decreases from 0.63 BCMs to 0.43 BCMs. In addition, the volatility measures increased during the cold season and decreased during the warm season. See Table 5 for details.

[25] We note that the costs of removing dams may be cost-prohibitive. A more realistic approach may be to use pulse or flush flows. This is the case on the Colorado River where the recently approved Minute 319 created a pilot program that required water users in the U.S. and Mexico to provide a one-time high-volume flushing flow (or pulse flow) of 129.5 MCMs. Similar implementation of pulse flows have been addressed in the literature, for example Gómez et al. (in press), Truong (2012), and Wu and Chou (2004).

of major water storage infrastructure on agriculture in the State of Idaho. We exploit the long-term patterns of water transfers between cold and warm seasons through the operation of major irrigation storage facilities, and we examine the impacts on natural ecosystems. We make three contributions to the literature: First, we construct and utilize an integrated, historical, county-level repeated cross section dataset of major water storage infrastructure projects in Idaho spanning most of the twentieth century. We identify the timing of operation and service area of each dam and use this information to investigate the extent to which the major water storage infrastructure helped to stabilize agricultural production. Second, we compile and use a decadal dataset of water rights and address the complicated, appropriative water governance structure in Idaho, a system that is typical in states in the arid and semi-arid western United States. Third, we utilize a unique, long-term dataset of water supply to identify both the natural and observed stream flows, the latter of which is under the influence of major storage facilities. We calculate the level of volatility for warm and cold seasons and overcome some of the difficulties introduced by the lack of long-term data on the ecosystem services provided by the natural environment.

The findings in this study provide some useful insight to the agro-ecological impacts of water infrastructure development on agriculture and natural ecosystems in the arid and semi-arid western United States. Our findings can help inform efforts in search of a better, more comprehensive way to evaluate artificial water storage facilities. On one hand, the prosperity of irrigated agriculture depends on the development of water storage facilities, particularly as we move into an era with heightened climatic uncertainty. Historically, the added water storage capacity has proven to be closely related to the water institutions in Idaho and in the arid and semi-arid West, where water distribution and use are intensively subject to governance and management under the prior appropriation doctrine. Any changes to these water storage facilities will not only impact crop productivities and agricultural landscapes, but may also disrupt the economies of rural communities and ultimately the stability of entire regions in the arid and semi-arid western United States. On the other hand, the goods and services provided by the natural environment may have been negatively impacted, largely due to the altered supply of water resources. Future research will illuminate the debate, and will hopefully provide more evidence of the long-term impacts of major water infrastructure on ecosystem services. The trade-off between the agricultural benefits and ecological impacts should lead to a set of more balanced policies in the future.

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Appendix A. Supplementary data

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