The Documentation of the Data and Processing Methods

used in

"Climate Change, Water Rights and Water Supplies: the Case of Irrigated Agriculture in Idaho"

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A.1 Water rights and farm boundaries

The water rights geospatial data are compiled by the Idaho Department of Water Resources (IDWR) and updated in a regular manner (last retrieved, February 2011). We use the *Place-of-Use* layer of the data, in which each polygon indicates the specific location where water is diverted for irrigation and put to beneficial use under a specific water right. This file contains the essential aspects of individual water rights, and includes the ownership, water right number, priority date, water source, place of use, point of diversion, water use purpose, maximum diversion rate and volume, geographic location, and physical boundary. A total of 46,369 irrigation-related water rights with unique identifiers have been determined. We merge the polygons in this layer in ArcGIS based on the ownership information and construct the “farms” as the basic unit of this analysis. The geographic center (that is, the centroid of the polygon) of the oldest water right within each farm is used as the geographic center of that farm.

We separate water users into three categories: individual, group (for example, water user association, canal company, and irrigation district), and non-agricultural irrigators. Non-agricultural irrigators are excluded from our analysis.[1] This merging process is done in terms of the rule of the appurtenance of a water right to the land, which is one of the fundamental principles of the Idaho law of water rights.[2] Under this principle, water is allowed to be diverted to the designated location as specified by each water right. As

[1] Non-agricultural irrigation water users include, but are not limited to, government at the federal, state and local levels, large trustees, school districts, churches, financial institutions, and etc. Exceptions are given to the water rights owned by local governments in terms of the IDWR’s list of irrigation districts and canal companies, who provide irrigation delivery services by law.

[2] Idaho Code § 55-101; Idaho Code Ann. §§42-101, -220(1948), and -1402 (Supp. 1974); *Follet v. Taylor Bros.* 77 Idaho 416, 425-426, 294 Pac. (2d) 111 (1959); Hutchins (1977).

noted, this method should be regarded as a 'second-best' approximation due to the lack of farm boundary data.

A.2 Farm-level land use features: Sampling and consolidation

Farm-level land use features include the water source, water right priority date, maximum diversion volume, cropping (rotation) pattern, crop value, and soil quality. We develop a sampling strategy to create this data set. First, we generate a uniform sampling grid across the irrigated landscape for the State of Idaho, with a distance of 0.1 miles (161 meters).[3] Then we overlay the sampling grid on the targeted layer to obtain point-wise information. In the end, the point-wise information is consolidated at the farm level.

For example, in order to identify the farm-level, short-term cropping patterns (that is, the types of major crops grown by each farm), we overlay the sampling grid on the Cropland Data Layers (CDL) of Idaho (2007-2011), which is compiled by the U.S. Department of Agriculture, National Agricultural Statistics Service (NASS). Each sampling grid will return a single crop type for each crop year. We focus on the fourteen major (non-fruit) crops surveyed by the NASS in Idaho: alfalfa, barley, corn, beans, hay (other hay/non-alfalfa), lentils, oats, onions, peas, potatoes, sugar beets and wheat (durum wheat, spring wheat, and winter wheat), which represents approximately 77.9% of total

[3] The distance is chosen by considering the basic features of land parcels in Idaho. Many land parcels in our water rights geospatial layers are in the primary grid pattern of quarter sections (0.5 miles x 0.5 miles), its integer multiple, or a portion of a disk residing within these quarter sections. 161 meters is approximately 0.1 miles, which allow us to collect 25 sets of point-wise information within a single quarter section. In addition, this sampling strategy is also commensurate with our current computational capacities. Details on data processing are available upon request.

cropland in Idaho.[4] For each farm we can calculate the total number of sampling points with the identified crop variety that falls in the major crop categories, and we compute the ratios of each major crop within each farm for each crop year. Next, the crop varieties in the five-year range are pooled together to represent the short term cropping pattern of each farm. [5]

Similarly, we overlay the sampling grid on the U.S. General Soil Map for Idaho (NRCS) in order to calculate soil quality. We use the Irrigated Land Capability Classification - Dominant Condition (ICCDCD) since the irrigated landscape is the focus of this study. [6] To identify the water source of each farm, we overlay the sampling grid on the *Place-of-Use* layer of water rights and choose the dominant water source within each farm. By contrast, the farm-level consolidated priority (that is, average priority date of water rights) is calculated in a slightly different way. We calculate an average priority date of the portfolio of all water rights for each farm.[7] We also identify the oldest water right of each farm. Under the current water governance structure, farmers are more likely

[4] The acre harvested data is calculated based on the 2010 Idaho Crop Summary (NASS). The total cropland data is based on the Agricultural Census for Idaho in 2007. The remaining portion (that is, 22.1%) can be attributed to tribal lands, lands managed by Federal or State agencies, or lands where farmers practice dry farming methods.

[5] We have tried different ways to compute the cropping pattern of each farm. We have used the identified crop varieties of each farm for the current year, which has caused serious multicollinearity issues in the regression analysis. We also used the identified crop varieties of the previous crop year. This method is not satisfactory, because the widely used rotation practice may lead to the omission of crop varieties and thus be irrelevant to the current-year crop choice, particularly for smaller farms.

[6] A lower ICCDCD value indicates a higher land quality. The non-irrigated Land Capability Class Dominant Condition (NICCDCD) will be used where the ICCDCD is missing.

[7] The consolidated priority date is based on (Priority Year -1700). The purpose is to reduce the magnitude of the constant term and does not have any impact on the estimated coefficients of the other variables. We note that the estimated parameters of the priority date represent a relative measure.

to execute such a right first, because farmers with senior water rights are entitled to divert water over those with junior water rights by law.

To represent the cropping decision, we calculate the (expected) crop revenue per acre, per farm. We assume that cropping decisions are made with regards to anticipated crop productivity levels (yields) and crop prices, and therefore our predictions are based on the crop prices and yields from the previous year(s) or the average values in the short term. The crop-specific prices and yields come from the NASS during the crop years from 2003 to 2010 (NASS). The data is available at the state level, and thus regional differences are likely omitted. [8] We calculate the year-to-year crop-specific revenue per acre, per farm (that is, the product of the crop-specific average yield and price) in each crop year and average over 2003-2010. We can therefore measure the annual average crop revenue per acre for each farm by using the identified proportions of crop varieties and the state-level crop-specific revenue per acre.

There are some drawbacks of this sampling method. Due to the overlapping water rights and the map-making errors that usually happen at the edges of individual water rights, some sampling points inevitably fall into the boundaries of two or more constructed farms. We re-assign these points to the farm with the largest area, which is consistent with the fact that farms with large areas (such as within an irrigation district or canal company) gain more flexibility to allocate and reallocate irrigation water. A

[8] Some crops, for example potatoes, may have more regionally disaggregated productivity levels and prices received. We have conducted a separate robustness check by incorporating more regional differences in productivity and price. We did not find any significant deviation from the findings we present in this article. However, we are more concerned about the consistency of using data of different geographic scales for different crops. Therefore, the regression with partially regionally disaggregated crop productivity data is not presented.

sensitivity analysis will be conducted to assess the strength of this approach.[9] In addition, the sampling method will leave out small farms or collect insufficient sampling points from them, which may not fully represent the operational features of these farms.

A.3 Climate (weather)

The long-term climate (weather) data are provided in the raster format from the PRISM Climate Group (PRISM). We overlay this raster layer with the farm data layer to identify the minimum temperature in April within each farm for one calendar year. This step is repeated for all the years between 1971 and 2000, and for the minimum temperature, maximum temperature, and precipitation, respectively. The mean and standard deviation of the aforementioned climate indicators are computed for each farm and used as the long-term climatic conditions at the beginning of each growing season. We have noticed that the differences in the climate and weather conditions at different locations within each farm are insignificant. Therefore, the weighted average by using the 0.1 miles-by-0.1 miles sample grid is not exercised in this case.

We only use the minimum temperature in April (evaluated at both the average and standard deviation during the period from 1971 to 2000) to represent the climatic conditions at the beginning stage of each growing season for the following reasons: 1) Annual minimum temperatures in April are highly correlated with other climate and weather variables at various levels (see Tables B.2-B.4); 2) Precipitation during the entire growing season provides little water supply for irrigated agriculture; 3) The minimum

[9] In the sensitivity analysis, we re-assign these points to the farm with the oldest priority date.

temperature is found to be more representative of the multi-decadal Pacific climate variability [*Brown and Kipfmueller*, 2012], which is in line with the focus of this study; 4) Crop choices are made in the early spring and are also generally irreversible. Therefore, the cropping decision is presumed to be more associated with early growing conditions.

We note that this high correlation between different climate (weather) variables may be attributed to the unique spatial distribution of Idaho's irrigated agriculture. As Figure 1 shows, the majority of the identified farms are found along the narrow tributary of the Snake River Aquifer. Under this situation, the climate (weather) condition may change accordingly with the gradual change in elevation, where the elevation decreases consistently from east to west. This situation may not be found elsewhere; however, a closer examination of the correlations between climate (weather) variables is recommended. In addition, the sole use of the minimum temperature in April helps reduce the complexity of incorporating various climate and weather variables and avoids the collinearity issue, which may result in wrong estimates of the impacts of the climate (weather) variables.

A.4 Surface water supply

We use the total available water during the growing season (from April to September) at the basin level to represent the long-term water supply conditions (NRCS). The total available water consists of the adjusted streamflow from April to September and the reservoir storage at the end of March. The adjusted streamflow measures the total amount surface water available for the growing season in individual basins. This is a quantity measure rather than a velocity measure. The storage at the end of March is a quantity measure as well, which represents the maximum total available carry-over from the reservoirs. The total available water contains, in effect, information regarding natural streamflow, reservoir carryover, and melting snowpack runoff, but does not account for reservoir evaporation, diversion, and return flow. We calculate the mean and standard deviation in each basin during the period from 1971 to 2000. The average total available water does not indicate any significant correlation with the average April minimum temperature (see Table B.2).

In order to account for the *ex ante* information on water supply, we use the April-September Water Supply Outlook Report (WSO) evaluated in April. This seasonal forecast of surface water supply is also generated at the basin-level, and is published by the NRCS. The forecast is presented as both a quantity and a percentage relative to a 25- or 30-year moving average of water supply conditions for the growing season (April-September). [10] We use the percentage level in order to avoid possible collinearity issues caused by the use of the mean adjusted streamflow. We also use the county-level drought emergency declaration in the previous year as an alternative indicator for the *ex ante* water supply information. The drought emergency declaration, although it generally affects only the water allocation in the current growing season within a county (Idaho Code § 42-222A), may signal a changing water supply situation for the *next* growing season. We should note that the *ex ante* information on water supply forecast is generally based on surface water supplies.

[10] We use the forecast of the "50% chance of exceeding", which is the most probable situation. The chances of exceeding are the probabilities that the actual volume will exceed the volumes in the table. See the WSO at the NRCS website for more information.

A.5 Ground water data

We obtain the ground water level data from the HydroOnline portal of the IDWR (IDWR, last retrieved November 2013). The data contains 82,801 observations for 31,913 wells in Idaho. [11] The spatial distribution of the irrigation wells is consistent with the irrigation water rights. Similar to the water rights geospatial data, the purpose of wells, including irrigation, domestic, commercial and industrial, injection, multi-family, and municipal, are identified in the data. We use the value of the water level below land-surface datum (LSD) as the ground water level from the wells with irrigation purposes. [12] The ground water level is the measurement of the depth to ground water, which is different from the water table, because the former value does not take into consideration the elevation. As the IDWR indicates, the ground water levels at the sites of individual wells are measured only on an as-needed basis.[13] Therefore, a majority of the wells may not have consecutive annual observations or may not have the most recent water levels.

The ground water level data are utilized in two different ways in this study. First, we identify the wells with observations after the year 2000 that list irrigation as the water use purpose, and calculate the average water level in these wells as the input point features.

[11] Duplicated entries for the same site in the same year by different agencies are removed.

[12] As far as we have learned, special standards are enforced with respect to municipal, domestic and municipal wells. There is, however, no specific standard for irrigation wells, although there may be areas where the IDWR will limit any irrigation well or require that a well go deeper to stay out of an aquifer with a declining water level. Therefore, it may be inconsistent to include the water level at the municipal, domestic and municipal wells.

[13] This was obtained through a personal conversion with Michael Ciscell of the IDWR on November 19, 2013.

There are 850 wells in this subset and 270 wells have at least five observations after the year 2000. We apply a Kriging method and interpolate the water levels at the sites of these irrigation wells into a surface raster to represent the current ground water levels in Idaho.[14] We thereby identify the ground water level at each farm based on its geographic location.

We select the irrigation wells with at least 20 years of observations in order to analyze the long-term change in the ground water levels. There are 865 irrigation wells in this subset, approximately 83% of which have at least one observation after 2000 and 63% of which have over 30 years of records. The longest duration of observation for a single irrigation well is 81 years. The earliest observation was recorded in 1908 and the most recent observation is dated 2013. We focus on the beginning and ending levels to reflect the historical changes of the ground water levels in the lifecycle of irrigation wells in Idaho. The beginning and ending levels of ground water depth are calculated as the average values of the first and the last five observations for these wells respectively. The summary statistics are presented in Table B.9.[15]

[14] Under an ideal situation we should be able to identify the irrigation wells and their associated ground water rights. However, this is not the case due to two major difficulties: (1) The hydro online data do not contain information regarding the associated water rights or the designated *place of use* for these wells. (2) More often than not, wells can be located outside a designated *place of use*. These situations have mad e it nearly impossible for us to link the irrigation wells with the irrigation water rights.

[15] We note that the summary statistics may be limited because of the possible non-continuous observation for individual irrigation wells.

A.6 Other data

To take into consideration the impacts of urbanization on agricultural land use decision making, we calculate the distance to the urban areas. The base layer is the Census 2010 Urbanized Areas. We overlay this layer with the farm layer and calculate the Euclidian distance from each farm to the nearest urbanized area.

Similarly, to obtain an approximation of the delivery cost, we calculate the distance of each farm to major water bodies. The base layers are the 1:250K scale polygons of rivers and lakes archived by the IDWR, which are presumed to be the major water bodies within the State. We overlay this layer with the farm layer and calculate the Euclidian distance from each farm to these water bodies and use the shortest value in ArcGIS.

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