Water Institutions and Agricultural Land-Use Change in the Western U.S.

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Introduction

- Ongoing climate change is expected to alter agricultural productivity, water demand, and the amount of water available for irrigation worldwide.
- Semi-arid regions are expected to become hotter and drier, with more variable rainfall, reduced surface water runoff, and reduced groundwater recharge. The Intermountain West in the U.S. is one such region. The majority of irrigation water is supplied by mountain snowpack, which is particularly vulnerable to climate change. There has been an observed trend towards more rapid snowmelt in the spring, followed by low flows in the late summer, at the time when water is most critical as an input into agricultural production.
- There is a need to develop "robust and flexible water allocation systems" that can facilitate producer adaptation and maintain agricultural productivity in the face of such change (FAO 2011). It is therefore critical to understand how existing water allocation institutions affect agricultural decision-making and the economic welfare of producers.

QUESTION

How do water rights institutions in the U.S. Intermountain West influence agricultural decision-making in the face of climate-driven changes in water availability?

Water Rights

- Understanding of the economic impacts of climate change on irrigated agriculture has proven elusive to date because water allocation institutions complicate the relationship between climate signals and decision-making at the individual level.
  - Climate and weather affect *water inflows*.
  - *Water availability* also depends on storage infrastructure and water rights, which govern who receives water and when.
- Water rights are complex and vary across states
  - Across the U.S. West, surface water is allocated across users according to the doctrine of prior appropriation ("first in time, first in right").
  - Irrigators hold usufruct water rights, each of which has a priority date that corresponds to the first date on which water was diverted for beneficial use.
  - In the event of a water shortage, senior water rights (those established earliest) are fulfilled first; junior water rights may be curtailed.
- Irrigators with junior rights face greater uncertainty in water availability than do those with senior rights, all else equal.
  - Because water availability is not known with certainty at planting, irrigators with junior rights will likely make different production choices than those with senior rights.
  - Planting potatoes or sugarbeets, high-valued crops that cannot survive a missed irrigation application, is risky given the prospect of curtailment. Irrigators with junior rights may be more likely to plant drought-resilient, low-value crops.
- Changes in the mean, variance, and timing of water inflows, along with population growth and urban expansion, have begun to test water rights institutions in never-before-seen ways.

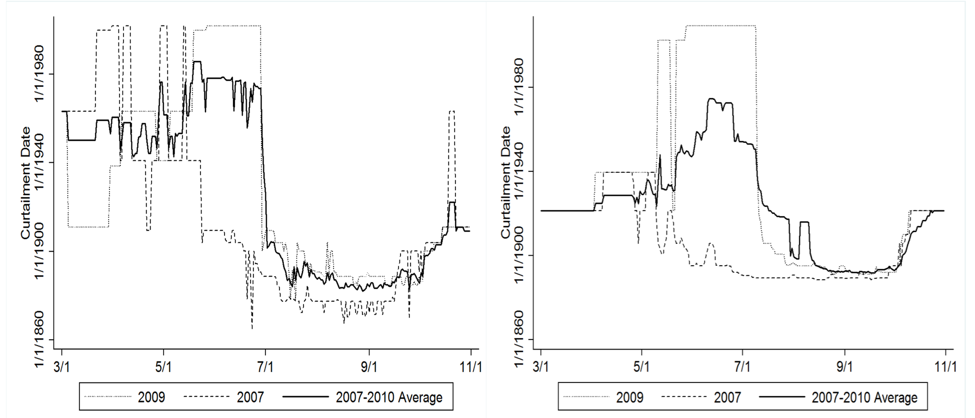

Figure 1. Curtailment Date by Day of the Growing Season along Two Reaches in the Middle and Upper Snake River Basins, 2007-2010

Notes: The curtailment date is the priority date of the last water right fulfilled on a particular day of the growing season and along a particular river reach. The panel on the left illustrates curtailment dates for Mores Creek above Robie Creek near Arrowrock Dam (site 13200000) in the Boise River System of the Middle Snake Basin. The panel on the right illustrates curtailment dates for the Snake River at Lorenzo (site 13038500) in the Snake River System of the Upper Snake Basin. Data are from the Idaho Department of Water Resources Water Rights Accounting database.

Study Region

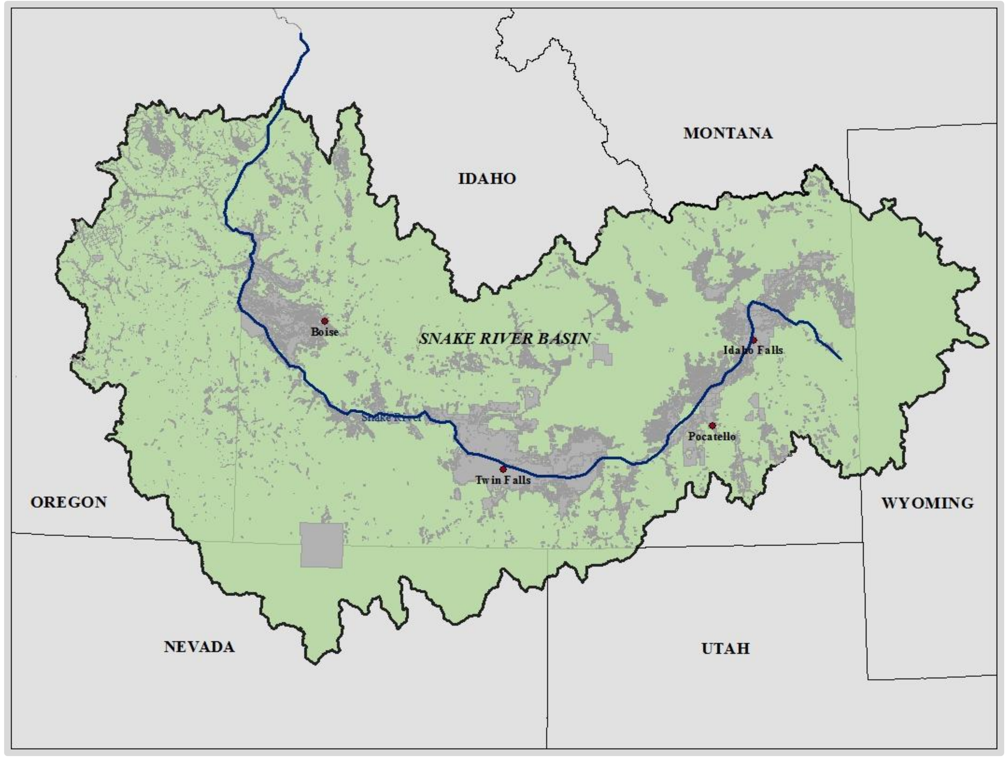

Figure 2. The Snake River Basin (in green) with Idaho and Oregon water rights for irrigation by place of use (in grey)

- Agricultural production
  - The total market value of agricultural production in Idaho is $5.7 billion ($2.3 in crops; $3.4 in livestock).
  - The predominant crops grown are alfalfa hay (37%), wheat (30%), barley (12%), potatoes (8%), and sugarbeets (4%).
  - Topography, climate, and soil quality are relatively homogeneous across the Snake River Basin (Hansen *et al*. 2011).
- Water Use
  - Idaho ranks 3rd in total water use nationally (Kenny et al. 2009).
  - The majority of water used in Idaho is for irrigation (85.6%).
  - The Snake River Basin is home to 2.1 million hectares of cropland, 1.5 million of which are irrigated (NASS 2007).
  - The average farm is 148 hectares, 109 of which are irrigated (73.5%).
- Water Rights Institutions
  - The region has similar physical and economic characteristics, but water rights institutions differ abruptly across state lines.
  - This study focuses on Idaho and Oregon. Differences in water rights institutions across the two states are summarized in Box 1.

Box 1. Differences in water rights institutions between Idaho and Oregon

Idaho	Oregon
❖ Prior appropriation doctrine firmly entrenched in Idaho constitution and supported by case law.	❖ The state initially followed riparian doctrine and later adopted prior appropriation doctrine by statute. Hybridized system continues to operate today.
❖ Temporary and permanent water rights transfers facilatated when the state established water banking as a beneficial use for water.	❖ Temporary and permanent water rights transfers between users are more difficult.
❖ Conservation goals are secondary to providing water for irrigation.	❖ The state has a history of ensuring adequate water is available for environmental purposes, e.g. fish conservation.
❖ Surface water and groundwater are conjunctively administered via prior appropriation doctrine statewide.	❖ Groundwater pumping may be regulated within one mile of a hydraulically connected surface waterway.

APPROACH

Integrate remote sensing data into an econometric analysis of factors that affect land-use decisions by agricultural producers, with a focus on the allocation of land between dryland and irrigated production.

Objective 1: Develop a micro-economic theoretical framework linking climatic variability and water rights to agricultural land-use decision-making

Assume that a risk-neutral producer uses a vector of inputs **x** to produce a single agricultural commodity. The commodity can be produced with irrigation or on dryland. The irrigated and dryland production functions are given by:

$$y^i = f^i(x_w, x_l^i) \qquad \text{and} \qquad y^d = f^d(x_l^d)$$

where y^i and y^d denote total irrigated and rainfed crop yield per unit area, $\mathbf{x}_l$ is a vector describing the land allocation to irrigated and dryland production, and x_w is the allocation of water to irrigated production.

A producer who operates under certainty chooses a land and water allocation to maximize profit for the growing season:

$$\max_{x_w, \mathbf{x}_l} \pi = p\left[y^i(x_w, x_l^i) + y^d(x_l^d)\right] - r_l(x_l^i + x_l^d) - r_w x_w$$

At the optimal land allocation, it must be the case that the marginal productivity of a unit of land in irrigated production equals the marginal productivity of a unit of land in dryland production:

$$\frac{\partial f^i(W, x_l^i *)}{\partial x_l^i} = \frac{\partial f^i(L - x_l^i *)}{\partial x_l^d}$$

where W is water available to the producer and L is the total amount of land available for agricultural production.

A producer who faces the possibility of having their water right curtailed expects to receive water deliveries in the amount of $W^c = g(R,a) \leq W$, where expected deliveries depend on expected water inflows into the region (R) and the seniority of the producer's right(s) (a). The effect of a change in water availability on the optimal allocation of land to irrigated production is given by

$$\frac{\partial x_l^i *}{\partial W} = \frac{-\partial^2 f^i(W, x_l^i *)/\partial x_l^i \partial W}{\partial^2 f^i(W, x_l^i *)/\partial x_l^{i2} + \partial^2 f^d(L - x_l^i *)/\partial x_l^{d2}} > 0$$

The theoretical framework yields three testable hypotheses: (1) all producers reduce irrigated production in a dry year; (2) a relatively junior irrigator allocates less land to irrigated production in any year, regardless of inflows; (3) in a dry year, a junior irrigator reduces irrigated acreage by a greater amount than a senior irrigator.

Objective 2: Develop an empirical econometric model to explain observed land-use decisions in the Snake River Basin

Our empirical strategy exploits the spatial discontinuities created by water rights boundaries and state boundaries to identify the effect of water rights seniority on land-use decision-making. The econometric model is given by:

$$Y_{jt} = \alpha + \beta_1 a_j + \beta_2 R_{jt} + \beta_3 (a_j * R_{jt}) + \mathbf{v}_{jt}\gamma + \mathbf{X}_{jt}\delta + \mathbf{Z}_{jt}\varphi + \eta_j + \varepsilon_{jt}$$

where j indexes the individual farm and t indexes the year. Model variables and data sources are defined in Box 2.

Box 2. Summary of model variables

	Variable(s)	Data Source
a	Water right seniority (priority date)	IDWR
R	Expected water inflows (seasonal forecasts and long-run climate normals)	USDA–NRCS
v	Other water right characteristics (place of use, season of use, water source, point of diversion)	IDWR
X	Site-specific characteristics that affect agricultural productivity (soil quality, topography, depth to groundwater, distance to nearest surface water body)	IDWR; USGS; USDA–NRCS
Z	Other variables that affect decision-making (prices, costs of production, temperature, population growth, distance to urban center, regional income)	USDA–NASS; PRISM; US Census Bureau

Notes: IDWR = Idaho Department of Water Resources.

Objective 3: Merge remote sensing data from MODIS and Landsat to generate a panel dataset of agricultural land-use observations

NASA remote sensing data provide the dependent variable in the econometric model (the observed outcome of a decision-making process), which will be summarized as the proportion of land irrigated within the geospatial boundaries of each farm.

We will distinguish between irrigated and dryland agriculture by examining the dynamics of greenness over the course of each growing season.

- Landsat data are at a spatial resolution consistent with individual decision–making units (farms) and the length of the time series allows us to capture changes in climate as well as weather. But the coarse temporal resolution and cloud cover are problematic.
- MODIS data are available at a finer temporal resolution and can be used to distinguish the profile of NDVI for irrigated versus dryland agriculture within a season. But the coarse spatial resolution and short time series are not ideal.

We will use MODIS and Landsat data in a complementary way following Ozdogan (2004) and Ozdogan et al. (2006). MODIS NDVI will be used to identify differences in the spectral signatures of irrigated and dryland late in the growing season (Figures 3 and 4). The NDVI threshold will be applied to Landsat images from July–September to categorize land use. Once classified, water rights boundaries will be overlaid on the Landsat data layers and the proportion of irrigated land within those boundaries summarized.

Validation and ground-truthing will include field visits and the use of ancillary datasets from the USDA–NASS and the IDWR. Validation will be undertaken when evaluating NDVI on irrigated and dryland parcels using MODIS data and to ensure that the final Landsat classification of irrigated and dryland agriculture is accurate.

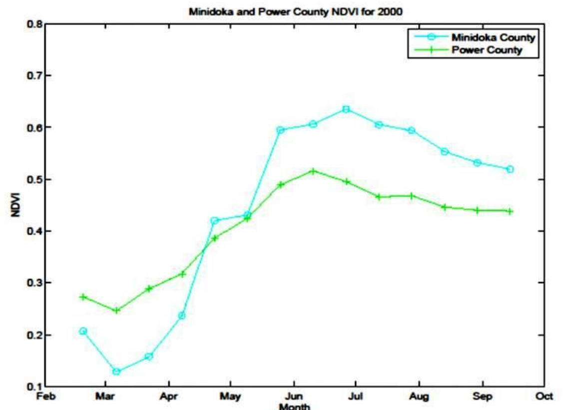

Figure 3. NDVI over the year 2000 growing season for Power County (69% irrigated) and Minidoka County (99% irrigated)

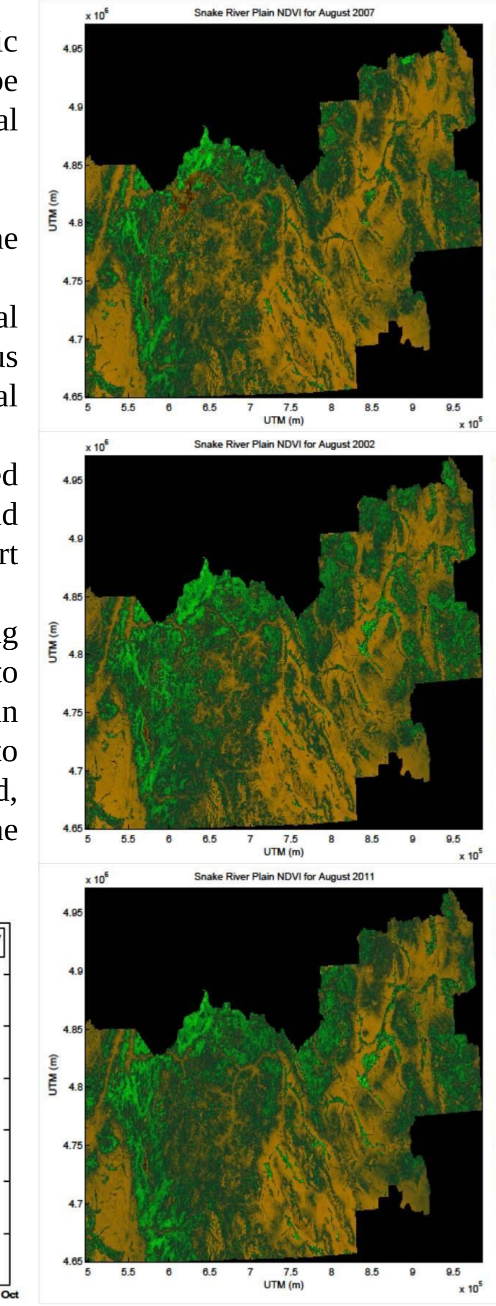

Figure 4. NDVI across the Snake River Plain of Idaho on August 13th of a dry year (2007), an average year (2002), and a wet year (2011)

Preliminary Analysis

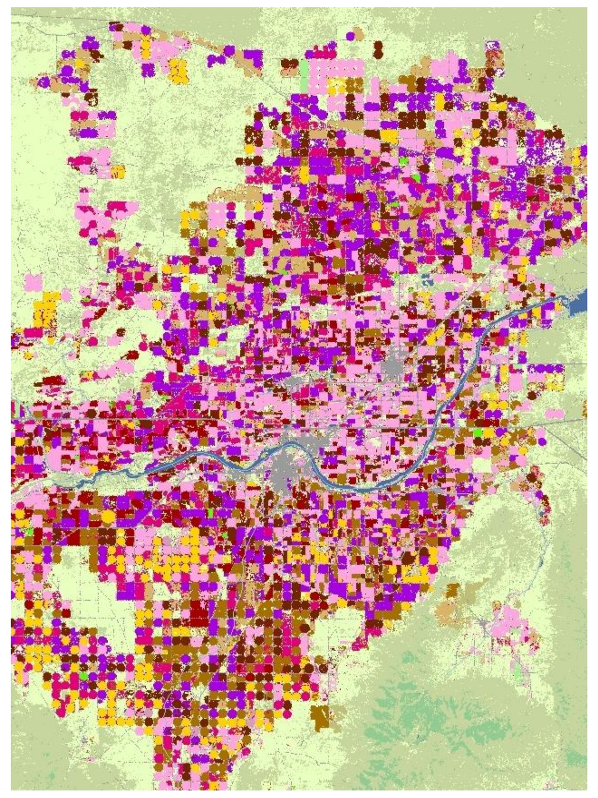

Figure 5. Crop cover near Twin Falls, Idaho in 2010

- A preliminary analysis was undertaken for the State of Idaho, including the Upper, Middle, and Lower Snake, Kootenai–Pend Oreille–Spokane, Bear, and Great Salt Lake Basins (Cobourn *et al*., in review).
- The dataset spans 46,369 unique water rights designed for irrigation and four growing seasons (2007–2010).
- Land-use decisions are summarized by USDA–NASS Cropland Data Layers.
  - Raster data layer at a spatial resolution of 56 meters describes each producer's choice of crops.
  - A spatial sampling technique is used to describe how land is allocated across 12 major crops within the boundaries of each farm.
  - The dependent variable in the econometric model is expected revenue.
  - Water use decisions are only captured insofar as some crops cannot be produced without irrigation (e.g. potatoes and sugarbeets, beans, and corn).
- Other variables included in the model are the mean and standard deviation of the seasonal water forecast (at the time of planting), long-run water availability, water right seniority (priority date), the mean and standard deviation of growing degree-days, soil quality, and distance from nearest surface waterway.

FINDINGS

- *Producers with access to a less stable natural water supply tend to plant lower-valued crops.*
- *Junior irrigators plant lower-valued crops than farms with earlier priority dates, but the effect diminishes after 1906.*
- *Farms with junior surface water rights are more responsive to an anticipated water shortage than farms with senior surface water rights. Junior and senior groundwater irrigators do not respond differently to an anticipated water shortage, which indicates that access to groundwater protects irrigators from uncertainty in inflows.*

References

- Cobourn, K.M., W. Xu, S.E. Lowe, and S. Mooney. The effect of climate, weather and water rights on land-allocation decisions in irrigated agriculture. In review.
- Food and Agriculture Organization of the United Nations (FAO). (2011). *Climate change, water and food security*. Web. 30 May 2012. http://www.fao.org/docrep/014/i2096e/i2096e.pdf.
- Hansen, Z.K., Libecap, G.D., & Lowe, S.E. (2011). Climate variability and water infrastructure: Historical experience in the western United States. In G.D. Libecap & R.H. Steckel (Eds.), *The economics of climate change* (pp. 253-280). Chicago, IL: The University of Chicago Press.
- National Agricultural Statistics Service (NASS). (2007). *Quick Stats: County Level Statistics, Census of Agriculture*. Web. 2 May 2012. http://www.nass.usda.gov/Data_and_Statistics/index.asp.
- Ozdogan, M. (2004). *The hydroclimatologic effects of irrigation in Southeastern Turkey* (Doctoral dissertation). Boston University, Boston, MA.
- Ozdogan, M., Woodcock, C.E., Salvucci, G.D. & Demir, H. (2006). Changes in summer irrigated crop area and water use in Southeastern Turkey from 1993 to 2002: Implications for current and future water resources. *Water Resources Management*, *20*(3), 467-488.

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