Title of Grant / Cooperative Agreement:	Water Institutions and Agricultural Land-Use Changes across the Western U.S.
Type of Report:	Summary of Research
Name of Principal Investigator:	Kelly Cobourn
Period Covered by Report:	7/25/2014-12/31/2017
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NASA Grant / Cooperative Agreement Number:	NNX14AH15G

Reference 14 CFR § 1260.28 Patent Rights *(abbreviated below)*
The Recipient shall include a list of any Subject Inventions required to be disclosed during the preceding year in the performance report, technical report, or renewal proposal. A complete list (or a negative statement) for the entire award period shall be included in the summary of research.

Subject inventions include any new process, machine, manufacture, or composition of matter, including software, and improvements to, or new applications of, existing processes, machines, manufactures, and compositions of matter, including software.

Have any Subject Inventions / New Technology Items resulted from work performed under this Grant / Cooperative Agreement?	No ◉	Yes ○
If yes a complete listing should be provided here: Details can be provided in the body of the Summary of Research report.		

Reference 14 CFR § 1260.27 Equipment and Other Property (abbreviated below)
A Final Inventory Report of Federally Owned Property, including equipment where title was taken by the Government, will be submitted by the Recipient no later than 60 days after the expiration date of the grant. Negative responses for Final Inventory Reports are required.

Is there any Federally Owned Property, either Government Furnished or Grantee Acquired, in the custody of the Recipient?	No ◉	Yes ○
If yes please attach a complete listing including information as set forth at § 1260.134(f)(1).		

Attach the Summary of Research text behind this cover sheet.

Reference 14 CFR § 1260.22 Technical publications and reports (December 2003)
Reports shall be in the English language, informal in nature, and ordinarily not exceed three pages (not counting bibliographies, abstracts, and lists of other media).

A Summary of Research (or Educational Activity Report in the case of Education Grants) is due within 90 days after the expiration date of the grant, regardless of whether or not support is continued under another grant. This report shall be a comprehensive summary of significant accomplishments during the duration of the grant.

Project objectives. The overarching goal of this project was to integrate remotely sensed land-use data into an econometric model to evaluate the impact of climate change and water rights institutions on agricultural land-use change across the Snake River Basin. To achieve this goal, we defined three supporting objectives that were accomplished during the project period, as outlined below.

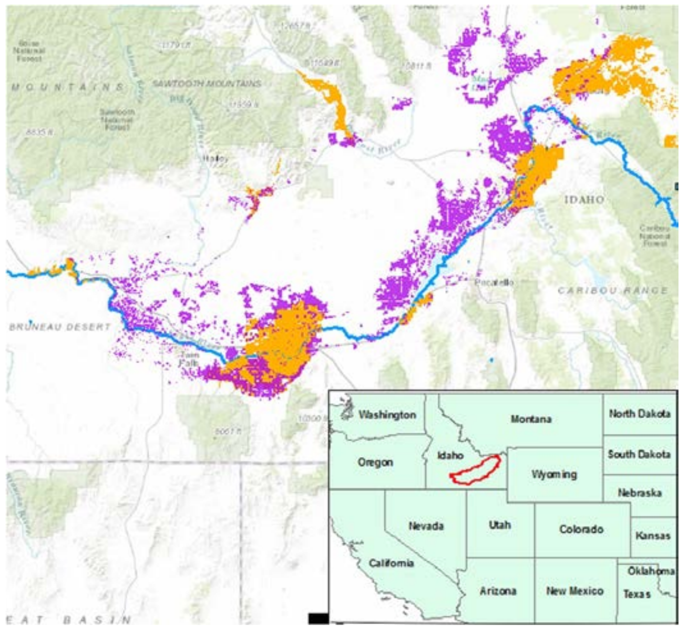
Objective 1. Develop a microeconomic theoretical framework linking climatic variability and water rights institutions to agricultural land-use decisions. Work on this objective has proceeded along four lines. In the first, we developed an economic theoretical model that demonstrates the effects of water and temperature on agricultural land allocation and farm profit (Ji, Cobourn, and Weng 2018). This model involves a constrained maximization problem in which farmers adjust land and water allocations when facing a changing climate, while taking into account physiological complementarities between temperature and water availability. We demonstrated that the way in which farmers adjust production in response to changing temperatures depends on the trade-off between two factors: 1) which crop is more suitable to grow under higher temperatures (the suitability effect); and 2) how higher temperatures affect a crop's demand for water (the physiological complementarity effect).

In the second line of inquiry, we developed new theory that uses a probabilistic approach to demonstrate how farmers with water right portfolios respond to climate-driven risk in water deliveries (Cobourn et al. 2018). In this theory, we show how the structure of a farmer's portfolio and the regional allocation of water rights together determine the probability that a farmer receives water deliveries during a growing season. We define farmer-specific probability density functions from which water right portfolios are constructed for each farmer, then describe a compound cumulative distribution function for water rights security across all farmers in the region. We use this CDF to define the regional curtailment date, which depends on climate and defines which farmers receive water or are curtailed to accommodate a shortfall in stochastic regional water inflows. Using this new theory, we developed empirically testable hypotheses that relate land allocation decisions with regional water availability and water right portfolio characteristics.

In the third area of inquiry, we examined how farmers develop expectations over stochastic natural factor inputs such as temperature, precipitation, and supplemental irrigation water (Ji 2018). We explored farmers' belief formation mechanisms in order to assess the impact of changing natural conditions, including climate change, on agricultural production and adaptation. Our starting hypothesis was that the belief formation processes are governed by strict Bayesian updating, a standard assumption rooted in microeconomic theory. Bayesian updating dictates that the posterior belief on water supply is primarily governed by long-run climate norms. Under Bayesian updating, a short-run shock in water supply has little impact on the posterior belief, and that small impact persists in subsequent years. We showed that for agricultural producers, Bayesian updating may not be an appropriate assumption when considering expectations over stochastic weather realizations. The actual impact of climate change should incorporate the potential loss from farmers' behavioral changes in response to short-run weather shocks.

In the fourth line of inquiry, we developed a simple, dynamic theoretical model of cooperative bargaining between surface and groundwater users (Cobourn, Amacher, and Elbakidze 2018). This analysis followed negotiations between surface water and groundwater users in Idaho, which highlighted a potential mechanism to resolve costly conflict that has arisen in many areas of the western U.S. where surface and groundwater resources are hydraulically connected. The model reflects the potential gains to both types of water users from bargaining over a sustained reduction in groundwater pumping to increase surface water flows. In a non-cooperative setting, surface water users choose the groundwater pumping reduction to maximize their net production rents, but doing so is costly, which creates an incentive for surface water users to negotiate with groundwater users.

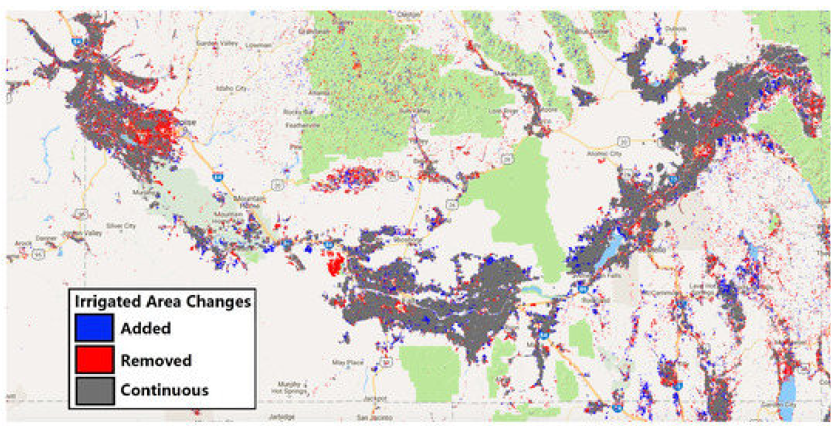
Objective 2. Develop an empirical econometric model to explain observed land-use decisions in the Snake River Basin. We developed and estimated several econometric models to explore farmers' land-use decisions in response to changing climatic factors. In one study (Ji and Cobourn 2018), we showed that irrigation districts alleviate that risk by deviating from the strict application of prior appropriation doctrine. As a result, farmers inside irrigation districts were able to plant more water-intensive crops than farmers outside irrigation districts, which increases profitability. For this analysis, we developed a georeferenced panel data set at the spatial scale of the individual water right from 2007-2014 for Idaho's Eastern Snake River Plain. Our econometric results indicated that on average, irrigation districts allocated larger portions of their land to drought-sensitive, high-value crops such as sugarbeets and potatoes. As a result of differences in planting decisions, members of irrigation districts earned on average $16.20 per acre, or 6.0% more per year, than those outside of irrigation districts.



Individual water rights (purple) and irrigation districts (orange) in the Eastern Snake River Plain of Idaho. Source: Ji and Cobourn (2018).

In a second study (Cobourn et al. 2018), we showed that water rights introduce heterogeneity in the risk of a water shortage among otherwise similar agricultural irrigators. This heterogeneity in risk gives rise to an economic inefficiency by constraining the land-allocation decisions of irrigators with less secure property rights to water. Using a fine-scale dataset of spatially referenced surface water rights for the Eastern Snake River Plain in Idaho, we found empirical evidence that those farms with the most secure rights chose a land allocation that involved less extensive fallowing and more drought-sensitive crops than those with less secure rights. We also examined whether access to different types of water right portfolios offset this difference. We found that ownership of a portfolio of water rights that diversifies across seniority was associated with a more profitable land allocation but did little to mitigate the effect of seniority. In contrast, a portfolio providing access to correlative water rights, such as those held by irrigation districts, offset the effect of seniority nearly entirely. This was likely due to numerous reasons, including more homogeneous risk sharing in correlative systems and access to informal water markets.

In a third study (Ji 2018), we acquired daily water curtailment data in the Upper Snake River Basin for 1980-2016. Using that, we calculatde the long-run probabilities of water curtailment and the yearly-aggregated short-run shocks in water supply for each water right. We paired those data with field-level crop allocation, temperature, and precipitation data by spatially matching each water right with high-resolution geospatial datasets on land allocation and climate from 2007-2016. Using this dataset, we empirically explored the effect of Bayesian updating of climate expectations on land-use decisions with a combination of regression-corrected matching and a difference-in-differences (DID) strategy. Our results indicated that for the year immediately after a climate shock, a farmer with a less secure water right allocated their land significantly more conservatively by putting less weight on water-intensive, higher-value crops compared to a farmer with a more secure water right. We estimated an average treatment effect of $34.2 per acre, or 12.8% of average annual profits. This result was contrary to strict Bayesian updating in the sense that that short-term shocks significantly affected farmers' beliefs and decision-making processes. For the second year after the shock, we found that differences in land allocation between the senior and the junior farmers was significantly smaller, with an average treatment effect of $7.4 per acre. This implied that the negative effect of a shock on belief faded in a short period of time.



Long-term change in irrigated area from 1984-2016 in the Snake River Plain of Idaho. Source: Chance et al. (2018).

Objective 3. Merge remote sensing data from MODIS and Landsat to generate a panel dataset of agricultural land-use observations and existing data on physical and economic factors that drive land-use decisions. To address this objective, we conducted two analyses of remote sensing data. First, we developed an improved irrigated land-use mapping algorithm that uses the seasonal maximum value of a spectral index to distinguish between irrigated and non-irrigated parcels in the Snake River Plain. We compared this approach to two alternative algorithms that differentiated between irrigated and non-irrigated parcels using spectral index values at a single date or the area beneath spectral index trajectories for the duration of the agricultural growing season. Using six different pixel and county-scale error metrics, we evaluated the performance of these three algorithms across all possible combinations of two growing seasons (2002 and 2007), two datasets (MODIS and Landsat 5), and three spectral indices, the Normalized Difference Vegetation Index, Enhanced Vegetation Index and Normalized Difference Moisture Index (NDVI, EVI, and NDMI). We demonstrated that, on average, the seasonal-maximum algorithm yielded an improvement in classification accuracy over the accepted single-date approach, and that the average improvement under this approach was a 60% reduction in county scale root mean square error (RMSE), and modest improvements of overall accuracy in the pixel scale validation. The greater accuracy of the seasonal-maximum algorithm was primarily due to its ability to correctly classify non-irrigated lands in riparian and developed areas of the study region.

In the second analysis, we built on the first to examine farmer responses to seasonal changes in water availability in the Snake River Plain for the time series 1984-2016. We applied a binary threshold based on the seasonal maximum of the Normalized Difference Moisture Index (NDMI) using Landsat 5-8 images to distinguish irrigated from non-irrigated lands. We found that the NDMI of irrigated lands increased over time, consistent with trends in irrigation technology adoption and increased crop productivity. By combining remote sensing data with geospatial data describing water rights for irrigation, we showed that the trend in NDMI is not universal, but differs by farm size and water source. Farmers with small farms that rely on surface water were more likely than average to have a large contraction (over −25%) in irrigated area over the 33-year period of record. In contrast, those with large farms and access to groundwater were more likely than average to have a large expansion (over +25%) in irrigated area over the same period.

Deliverables. To date, the project has produced six papers (3 published in peer-reviewed journals, 1 in revision, 2 in preparation); three graduate theses and dissertations (2 M.S. theses, 1 dissertation), and 13 professional presentations. Results of the analysis have been disseminated to diverse audiences, including stakeholder groups in the Snake River Plain (Idaho Department of Water Resources, University of Idaho Extension, regional water consultants, and farmers).

<u>Papers</u>

Chance, E.W., K.M. Cobourn, and V.A. Thomas. 2018. "Trend Detection for the Extent of Irrigated Agriculture in Idaho's Snake River Plain, 1984-2016," *Remote Sensing*, 10:145.

Chance, E.W., K.M. Cobourn, V.A. Thomas, B. Dawson, and A.N. Flores. 2017. "Normalized Difference Moisture Index Method for Identifying Irrigated Areas in the Snake River Plain, Idaho," *Remote Sensing*, 9: 546.

Cobourn, K.M., X. Ji, S. Mooney, and N.F. Crescenti. "The effect of prior appropriation and water right portfolios on agricultural land-allocation decisions," revise and resubmit at *American Journal of Agricultural Economics*.

Cobourn, K.M., G.S. Amacher, and L. Elbakidze. "Bargaining for Recharge: An Analysis of Cooperation and Conjunctive Surface Water-Groundwater Management," in preparation, *Water Resources Research* (submission April, 2018).

Ji, X. and K.M. Cobourn. 2018. "The economic benefits of irrigation districts under prior appropriation doctrine: an econometric analysis of agricultural land-allocation decisions," *Canadian Journal of Agricultural Economics*, doi:10.111/cjag.12165.

Ji, X., K.M. Cobourn, and W. Weng. "The effect of climate change on irrigated agriculture: water-temperature interactions and adaptation in the western U.S.," in preparation, *Land Economics* (submission April, 2018).

<u>Theses and dissertations</u>

Chance, E.W. 2017 (June). Irrigator responses to changes in water availability in Idaho's Snake Plain Aquifer. Masters thesis, Forest Resources and Environmental Conservation, Virginia Tech. (Co-Chair: V. Thomas, Forest Resources and Environmental Conservation)

Dawson, B. 2014 (December). Developing and testing a greenness-duration method for mapping irrigated areas: a case study in the Snake River Plain. Masters thesis, Geosciences, Boise State University. (Co-Chair: A. Flores, Geosciences, Boise State University)

Ji, X. 2018 (August, expected). Prior appropriation water rights and land-use decision making in the Eastern Snake River Plain. Doctoral dissertation, Forest Resources and Environmental Conservation, Virginia Tech.

Presentations

Ji, X. and K.M. Cobourn. How do Farmers Adapt to Stochastic Input Shocks? Evidence from a Quasi-Experiment of Water Curtailment under Prior Appropriation. Selected Presentation, Agricultural and Applied Economics Association Annual Meeting, Washington, DC, August 2018.

Ji, X., K.M. Cobourn, and W. Weng. The Effect of Climate Change on Irrigated Agriculture: Water-Temperature Interactions and Adaptation in the Western U.S. Selected Presentation, Agricultural and Applied Economics Association Annual Meeting, Washington, DC, August 2018.

Ji, X., K.M. Cobourn, and W. Weng. The Effect of Climate Change on Irrigated Agriculture: Water-Temperature Interactions and Adaptation in the Western U.S. Selected Presentation, World Congress of Environmental and Resource Economists, Gothenburg, Sweden, June 2018.

Cobourn, K.M. "Bargaining for recharge: an analysis of cooperation and conjunctive surface water-groundwater management," Selected Presentation, Soil and Water Conservation Society Annual Meeting, Madison, WI, July-August 2017.

Cobourn, K.M., X. Ji, S. Mooney, and N. Crescenti. "Water right seniority, economic efficiency, and land allocation decisions," Selected Presentation, Agricultural and Applied Economics Association Annual Meeting, Chicago, IL, July 2017.

Ji, X. and K.M. Cobourn. "Water availability, land allocation, and the role of irrigation districts under prior appropriation doctrine," Selected Presentation, Agricultural and Applied Economics Association Annual Meeting, Chicago, IL, July 2017.

Cobourn, K.M., X. Ji, S. Mooney, and N. Crescenti. "Surface Water Rights and Land Allocation Decisions: A Fractional Multinomial Logit Analysis using Field-scale Remote Sensing Data," Invited Presentation, Michigan State University, October 2016.

Cobourn, K.M., X. Ji, S. Mooney, and N. Crescenti. "Surface Water Rights and Land Allocation Decisions: A Fractional Multinomial Logit Analysis using Field-scale Remote Sensing Data," Invited NASA Land-Use/Land-Cover Change Webinar, June 2016.

Cobourn, K.M., X. Ji, S. Mooney, and N. Crescenti. "Surface Water Rights and Land Allocation Decisions: A Fractional Multinomial Logit Analysis using Field-scale Remote Sensing Data," Invited WAEA/CAES Symposium Presentation, Western Agricultural Economics Association/Canadian Agricultural Economics Society Joint Annual Meeting, Victoria, British Columbia, June 2016.

Cobourn, K.M., G.S. Amacher, and L. Elbakidze. "Bargaining for Recharge: An Analysis of Cooperation and Conjunctive Surface Water-Groundwater Management," Invited AAEA Presentation, Allied Social Science Association Annual Meeting, San Francisco, CA, January 2016.

Cobourn, K.M. “Prior Appropriation Water Rights and Land Allocation Decisions in Irrigated Agriculture,” Invited Presentation, Virginia Tech Civil and Environmental Engineering, Blacksburg, VA, April 2015.

Cobourn, K.M. “The Effect of Appropriative Water Rights on Land Allocation Decisions in Irrigated Agriculture,” Invited Presentation, University of Florida Food and Resource Economics Department, March 2015.

Cobourn, K.M. and A. Flores. “Prior Appropriation Water Rights and Climate Change Adaptation: Using Remote Sensing Data to Evaluate Long-Run Changes in Land and Water Use in the Eastern Snake River Plain," Invited Presentation, Agricultural and Applied Economics Association, Minneapolis, MN, July 2014.