Do Secure Property Rights Affect Resource Allocation and Firm Production? Evidence from Water Right Adjudications in Idaho.

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Abstract

Ambiguity in property rights is seen as a barrier to functioning water markets in the Western United States and Globally. States have attempted to resolve this through 'General Basin Adjudications', a legal process which formally verifies and redefines which individuals in a basin have valid water rights, how much water they are entitled to, and who has priority receiving water during a shortage. Using a novel combination of administrative water right data and remotely sensed soil and crop data, I evaluate the impact of one such adjudication in the Idaho. Between 1987 and 2013, The Snake River Basin Adjudication adjudicated over 139,000 water rights at a cost to the State of over $94 million. I use differences in the timing of adjudication between sub-basins to identify the short run impacts of adjudication. By reducing transaction costs, adjudication leads to an increase in the rate of permanent sales of water rights by 170%. There is also an increase in the short-term leasing of water rights, but this is less cleanly estimated. Based on measures of soil and climate characteristics, these transfers move rights from parcels of land which have relative comparative advantage in non-irrigated agriculture to parcels of land who have comparative advantage in irrigated agriculture. After water rights are transferred, buyers of water rights start growing higher value crops, whilst sellers do not have a significant change in production patterns, implying aggregate gains from trade.

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1 Introduction

Like many arid regions, the availability of water in the Western United States imposes a binding constraint on agricultural production, as well as other economic activities. In the presence water scarcity, societies have mechanisms to allocate water among competing users and end uses. The legal doctrine governing this Mechanism in the Western United States is that of 'Prior Appropriation'. This doctrine has two key components: The first is that individuals can maintain the right to 'use' (but not own) water rights by diverting water and continuing to put it to 'beneficial use' every year. The second component is that during a drought, a strict priority in water use is given to users who historically began diverting water first. The 'Prior Appropriation Doctrine' gives rise to a system of water rights that are in principle detachable from land and transferable. If not for prohibitive transaction costs, many economists argue, these water rights could potentially form the basis for functional water market in the West which would give rise to more efficient water use[1]. These arguments typically invoke insights of Coase (1960); that when property rights are clearly defined, mitigating transaction costs leads to more efficient resource allocation.

However, some Western States have failed to develop institutions to support 'Prior Appropriation' on several fronts; Firstly States have failed systematically collect and maintain records of water rights existing and in use. Secondly, many States failed to enforce water rights in a meaningful way. Thirdly States have not developed institutions which reduce transaction costs or facilitate water right transfers. In the absence of State institutions, the actual mechanisms allocating and managing water use are much less clear to outside observers. In practice a combination of both formal and informal local institutions (irrigation and water districts, community groups), as well as federal projects (damming and management by USBR) have stepped in to fill in the void. Elinor Ostrom (1995), who has written extensive case studies documenting communal solutions common pool resource problems, argues that locals are often able to overcome these coordination problems around common pool resource by developing self-enforcing local institutions, and thus leading to efficient use of resources. In this view of the world State intervention in these institutions might be deaf to idiosyncratic local water needs and might lead to less efficient resource allocation.

This paper examines the tension between these two views through the lens of 'General Basin Adjudications' a legal process which attempts to reform water management within a State by clearly defining and

[1] For example see Culp et al. (2014) or Anderson and Snyder (1997)

enforcing the water rights of each individual. In an adjudication, a specialised water court formally audits all water users within a River Basin and redefines who has a valid 'Water Rights', how much water they are entitled to, and who has 'priority' receiving water during a shortage. Adjudications are typically combined with reforms to clarify water law, and processes to improve the enforcement of water priority. Such processes might include the appointment of State Water Engineers and Basin Water Masters responsible for managing water use, the use of State sanctioned hydrological models to asses water availability in a particular year, improved metering practises and the processes for streamlining the assessment and approval of water right transfers.

Under a Coasian view, we might expect adjudication to clarify property rights thereby reducing transaction costs. We might expect this to lead to an increase in the transfer and leasing of water right, and that these transactions would reallocate water rights towards parcels of land that have soil and climate characteristics which give them comparative advantage in irrigated production compared to non-irrigated production. We might expect this to lead to an intensification of the sorting of farmers crop choices with respect to the seniority of their property rights. We also expect that the reduced uncertainty around each individuals legal water allocation might spur more investment in farm machinery and improvements and that the increased productivity of agricultural land would be captured in agricultural land values.

On the other hand, to the extent that communities develop institutions to overcome the common pool problems in ways that are not easily observed, water management might already be approximately optimal and the benefits form adjudication might be significantly smaller.

This paper uses the adjudication of the Snake River Basin Adjudication (SRBA) in Idaho as an empirical setting to examine the impact of water right adjudications. Beginning in 1987 and finishing in 2014, the SRBA is the largest water rights adjudication ever undertaken in the Western United States. The Snake River covers 87% of Idaho's land area and 90% of its water use. Within this basin, Idaho adjudicated 149,000 individual water rights. This corresponds to a water court settling approximately one court case every 90 minutes for 24 years[2]. Alternatively, the adjudication involved one court case for every ten persons living in the State of Idaho. The State spend of $94 million on the legal proceedings associated with the adjudication. The majority of the adjudicated water rights involved 'de minimis' Domestic and Stock-water whose adjudication water straightforward because they use a trivial amount of water. However, the case also settled over 38,000 Irrigation Rights which account for the majority of the Idaho's consumptive water use.

This paper estimates the impact of water right adjudication on patterns of water right trading and farmer

[2]This observation was made by U.S. Supreme Court Justice Antony Scalia at the conclusion of the SRBA

crop choices. To evaluate this adjudication I construct an individual level dataset from a novel combination of sources. I merge GIS data from the Idaho Department of Water Resources (IDWR) which specifies the water rights of each individual in the State along with the exact parcel of land on which those water rights are used and the adjudication history and the history of water right transfers and leases. I also merge in climate data and soil data from the USGS which are used as proxies for the productivity of any given parcel of land. Finally I merge in USDA's remote sensed crop data layer from which I infer the choice of crop and acreage decisions of each farmer given their water rights. Finally, to determine whether the adjudication has any aggregate impacts I also evaluate county-level data from the Census of Agriculture to infer how adjudication has impacted farm profitability, land values and on-farm investment decisions.

To identify the impact of the adjudication, I use two different strategies. Firstly, I look at differences in the timing of adjudication across different sub-basins within Idaho. To simplify the proceedings of the adjudication, the adjudication was broken into 35 sub-basins which were then adjudicated in a quasi-sequential fashion. This allowed the water court to focus it's limited resources on only adjudicating only 3-4 basins at a time. After these basins were adjudicated, legally binding 'partial decrees' were issued determining the water rights of all individuals in that sub-basin. The differences in the timing of the adjudication of water rights between basins as a result of the sequential adjudication us used to identify the causal, short run impact of water right adjudication.

Secondly to assess more aggregate impacts of adjudication I compare aggregate outcomes from adjudicated counties within Idaho, to neighbouring counties outside of Idaho (in Washington, Oregon, Utah, Montana and Wyoming) to evaluate the impact adjudication on aggregate economic variables from the Census of Agriculture.

My results are as follows: Firstly, I find that adjudication leads to significant increases in the rate at which water rights are permanently transferred, but not in the rates at which they are leased. I find that the increased rate of transfers is concentrated entirely among irrigation water rights rather than non-irrigation rights. Furthermore after adjudication the increase in the rate of transferred is largest among junior and groundwater rights, precisely they type of water rights whose security is ex-ante uncertain and likely to be clarified by adjudication.

Secondly, although ex-ante more senior rights holders grow crops which are more water intensive (since these individuals have older rights which are less likely to be curtailed), after adjudication there does not appear to significantly change in these patterns.

Thirdly, I compare the characteristics of parcels of land that sold water rights to the characteristics of parcel of land that bought them. I find that on average the parcels of land who buy water rights have characteristics which would be typically be associated with more productive agricultural land. Furthermore, after a water right transfer takes place, the parcel of land that bought the water rights begins growing more crops and more productive crops, whilst I cannot find a significant difference in the water consumption of the parcel of land that sold the water rights. This suggests an aggregated increase in economic output.

Finally, Using Census of Agriculture Data, I find that adjudication of water rights has no aggregate impact on land values or the profitability of farms. However this conclusion is drawn from aggregate county level data and the estimates are not precise enough to rule out large effects.

This paper contributes three growing literature's in economics: Firstly it contributes to a growing empirical literature which uses observational data to establish causal impact of variations in property rights on economic outcomes. Typically these papers have looked at study property rights over land, because it's of the pervasiveness, and economic importance. These papers typically generate quasi-random variation in property rights by either looking at variations generated by political reform Alston, Libecap and Mueller (2000), Libecap and Lueck (2011), Galiani and Schargrodsky (2010), or from cross sectional variation driven by political connectedness, Goldstein and Udry (2008), or from variation driven by technological change Hornbeck (2010). This literature gives an empirical backing to theories of property rights and transaction costs log established in the literature by Coase (1960) and Demsetz (1967).

Secondly it contributes to our understanding of the role transaction costs play in property rights systems. Although there is a large finance literature which uses bid-ask spreads to estimate transaction costs(**?**), Libecap (2016) argues that this is understudied within environmental economics. Some examples of applications within environmental economics are pollution markets (Stavins, 1995),(**?**) and fisheries **?**. Most recent and relevant to this paper is **?** who studies the role transaction costs play management of groundwater in California.

Finally this paper contributes to a literature trying to better understand the workings of water markets and how they affect economic outcomes. There is mixed evidence on the extent to which water rights are capitalized into land values, Mukherjee and Schwabe (2014) finds this is the case in Califorina, whilst Brent (2016) finds no evidence in Washington State. Althogh he does not frame it as such, Debaere and Li (2016) estimates the impact of the Rio-Grande Adjudication. However the weakness is that he us using highly aggregate county-level data with questionable controls. My paper is closely related to Xu, Lowe and Zhang (2014) Ji and Cobourn (2017) who instead matching water rights to crop choice using individual level remote sensed data.

The rest of this paper is organised as follows; Section 2 gives further background. Firstly about the legal standing of water rights and The Prior Appropriation in the Western United States and Secondly about the particular history of the Snake River Basin adjudication. Section **??** outlines a theoretical framework with which to understand the relationship between water right uncertainty, transaction costs, water right transfers and farm level crop choice. Section 3 describes the data that used in the empirical analysis. Section 4 outlines the empirical strategies use to analyse the data. Two approaches are taken to estimate the impact of water rights on adjudication; Firstly a reduced form approach, which uses a panel variation in the timing of adjudication to estimate whether adjudication affects the rate at which water rights are traded. Secondly a multinomial logit model estimates the impact adjudication has on crop choice and sorting of water rights to land quality. Section 5 describes the results and Section **??** discusses these results and draws conclusions.

2 Background

This section fills in a further context and background necessary to understanding the empirical exercise in this paper.

2.1 Water, Water Rights and Prior Appropriation

States are the legal owners of water in the US and they have the directive to manage water use for the benefit of their citizens. However each State has evolved different institutions to manage water depending on the different economic and social pressures that they face. There are two main legal doctrines which govern water use in the Western United States, In States that lie east of the 100th meridian, water rights are governed by the 'Riparian Doctrine', adopted from British common law which dictates all landowners who are riparian to a body of water (whose land abuts the water) have the right to make 'Reasonable Use' of that water[3].

This law was not sufficient to cope with water scarcity in the arid Western US, it was frequently contested how to share, and what constituted 'reasonable use'. Furthermore limiting water use to parcels of land abutting rivers greatly restricted the area and quality of land available for irrigation[4]. As a result a new legal doctrine, that of 'Prior Appropriation' was adopted in Idaho and other States lying on or west of the 100th Meridian[5]. In this system individuals hold 'Usufructuary water rights', rights to use (rather than own) water.

There are two key parts to the 'Prior Appropriation Doctrine': Firstly, an individuals who diverts water and puts it to 'beneficial use' gains the right to continue using that water in the future, so long as they continues to make 'beneficial use' of the water. Initially the term 'beneficial use' was interpreted to include only economically productive uses of diverted water; such as mining, agriculture or residential consumption. However over time legal interpretation beneficial use has expanded to recognise storage, recreation and environmental preservation as valid 'beneficial uses'.

The second part of the doctrine is the 'priority' principle. The first individual historically in time to

[3] This discussion is based on Getches (2009)

[4] Leonard and Libecap (2016)

[5] The 100th meridian runs from Texas to North Dakota, The other prior appropriation States are: California, Oregon, Washington, Idaho, Nevada, Montana, Wyoming, Colorado, New Mexico, Utah, Arizona, Texas, Oklahoma, Nebraska, South Dakota, North Dakota.

divert water is said to be the 'senior appropriator' and has the right to use water before more 'junior' appropriators in years where there is insufficient water to satisfy all competing demands. In practice this means that if a rights holder does not have enough water to satisfy his 'right' in a particular year he can make a 'call' requiring all junior users upstream of him to curtail their water use. If upstream 'juniors' do not respond by curtailing their use, he can seek to have the call enforced either through the State courts or water department.

Historically this system has several key benefits, by allowing water to be used on pieces of land not abutting a river, it brought larger areas of productive into irrigation. Furthermore this system protects the large investments required build irrigation infrastructure. In the absence of Prior Appropriation, farmers risked that their water might be lost in the future water users who divert away their before it can reaches, stranding their investment in irrigation infrastructure. Prior appropriation protects against this risk, thus providing an incentive to invest in irrigation infrastructure[6].

However today, most watercourses in prior appropriation States, including Idaho have been fully appropriated, so the main implication of this 'First in Time, First in Right' principle isn't that it secures investment. Rather the implication is that it creates a hierarchy of property rights. The holders of the first 'senior' water users will always receive these water rights before later 'junior' appropriators. Water rights with different vintages receive water with different probabilities. This might affect what the best economic use of the water is; Senior rights might be better applied to grow crops which are highly sensitive to the supply of water. Whereas more junior rights might be used to grow crops which are more drought resistant, or easily fallowed.

2.2 Enforcement of Water Rights

As discussed above, to obtain water right one merely has to divert water and apply it for beneficial use. However, these rights are of limited value if they are not acknowledged or enforced by State institutions. Unfortunately States have historically kept poor records of their water rights which has made enforcement difficult[7]. There are several reasons why this has happened: Firstly measurement of water of both current and especially historical patterns of water use has proved challenging for States. Event today water meters

[6]These mechanisms are discussed theoretically by Burness and Quirk (1980) and Empirically by Leonard and Libecap (2016)

[7]California is an extremely example of poor management of it's system of Water Rights. California's State Water Right Database has not been systematically verified and as a result consists largely of paper rights. Currently there are 10 times more claims to water rights in California than there is water in an average year Grantham and Viers (2014). Many of these claims are unverified, exaggerated or incomplete. The problems posed with enforcement of this are highlighted by the recent drought in California where in order to conserve water the Governor was forced to Mandate that all water rights users regardless of Priority reduce their water use by 20%, a decision which effectively undermined the integrity of the Water Right System.

are not common in agricultural settings. Secondly, States have historically not dedicated sufficient resources to the local institutions which manage water such as courts to adjudicate water rights, or local engineers and water masters to record and enforce water use patterns. Finally there are complex interdependencies in water use which often make it hard to understand how the enforcement of one individuals water use might affect the water supply to others in the basin. However improvements in the ability to model hydrology and measure water use through both meters and remote sensing have made these problems far more surmountable today than they were historically.

If water rights are not formally defined by the State, or their enforcement is costly or uncertain, then this can have adverse effects of the efficiency use of water. Users might be unwilling to change their water use patterns from the status-quo if changes might call the legal status of their right into question. Before a water right transfer is approved, parties to a transfer might need to not only demonstrate their own water right (by proving their claims to continuous use all the way back to their priority date), but also prove that there will not be any adverse third party affects or objections, which might require complex horological modelling and can be even more difficult if it is not known who these third parties are. This uncertainty can deter investment in the construction and maintenance of irrigation infrastructure, affect farms decisions about which crops to plant, and create transactions costs which prevent reallocation of rights to their highest value uses.

Disputes over water rights often end up involving many secondary parties because water use is interdependent across a whole basin. Often it can be difficult to resolve a dispute without understanding the implications for all affected water users, which might be everybody in the basin. As such resolving disputes over water rights can be extremely expensive if done on an ad-hoc basis. This results in significant fixed costs and risks for changes in water use or water right transfers, which often risk third party objections or disputes.

2.3 What is an Adjudication

Many experts believed that the most effective way to resolve disputes within a basin is to determine rights within a watershed is to conduct a General Basin Adjudication, where the claim of every individual within a watershed is verified, the independence of each water right determined and a hierarchy of water rights established in a binding legal manner[8]. A General Basin Adjudication generally involves the following steps. First the State creates a water court and appoints a judge responsible for overseeing the adjudication.

[8] Macdonnell and I (2015) discusses the evolution of thought within the Legal community of the effectiveness of General Stream Adjudications. Notable in his discussion is the lack of empirical evidence of the efficacy of adjudication.

Secondly all water users are expected to submit to the court claims of their water rights and evidence as to their pas water use under that rights. Thirdly the court audits all claims and determines each individuals water right, including the quantity and nature with which they have a right to use water and the priority order with which their water is rationed during a drought.

2.4 Water Right Transfers

Water rights are in principle transferable between parcels of land and can be changed in other water (such as ownership, nature of use or diversion point)[9]. Transfers of water rights increase the efficiency of water use by allowing it to be moved to the parcels of land on which it is most productive. However, all these changes must be approved by the State who typically require that such transfers do not have any harmful third party effects[10]. In practice this is often not easy for the following reasons: firstly transfers risk disputes which as described above can be costly to resolve. Because of these risks associate with transfers, States are often highly conservative in the conditions under which they permit transfers. Resulting in large bureaucratic hurdles to water right markets, which often require hiring expert consultants to vouch that transfers of water rights will not have adverse third party effects. Secondly, water right markets are thin. In States such as Idaho the number of users wanting to buy or sell water at any given time is relatively small. Transfers are typically conducted through agents (typically water lawyers) who will reach out to other other parties who might be interested in buying or selling a water right.

Adjudication makes these transactions easier by reducing the burden on sellers of water rights to demonstrate their historic use and ownership of rights and that their transfer will not impact others. In the past this would require sellers to engage in costly historical research and hydrological modelling. Post-adjudication water rights are understood by the State and they have their own hydrological models to simulate the impact of transfers.

In the State of Idaho, the water right transfer process is as follows: An individual submits a application for a water right transfer to IDWR and pays an application fee somewhere between \$200 - \$2000 dollars depending on the volume of the Water Right. Typically this fee constitutes a small part of the the dollar amount paid for the water right since the transfer may be prepared by a professional, typically a water lawyer

[9]Note that Agricultural Water Rights usually are transferred with the land when a farm is bought or sold. When I refer to water right ‘transfer’,‘trades’ or ‘leases’ in this paper I am referring specifically to the case where the matching of a Water Right with the parcel of land on which it is used changes.

[10]Even across ‘Prior Appropriation’ States there is significant heterogeneity in the laws, Szeptycki et al. (2015) gives a State-by-State review of water transfer and the degree to which they facilitate water markets. Some ditch companies and irrigation districts impose transfer restrictions water right transfers. Ghimire and Griffin (2014). In California some counties impose restrictions on transfers outside of the county Hanak (2003).

and may involve evidence from a consultant engineer or hydrologist. IDWR will first simulate the water right transfer in one of it's basin models to determine if it has any third party impacts. If there are third party impacts, the water right transfer must make plans to mitigate these impacts and get the approval of impacted parties. If a basin has not been adjudicated the onus is on the party wanting to undertake the transfer to determine who these third parties might be (since they are not necesscarily documents) and demonstrate that they are not impacted by transfer. If the water right transfer is approved, then When a water right is transferred, notification must be published in two local newspapers for at least 10 days[11]. If nobody objects after the announcement of the transfer, then the transfer proceeds. If the water right transfer is disputed then the parties wanting to make the transfer can either devise a mitigation plan to the satisfaction of the objecting party, or settle the dispute in either mediation or a water court[12]

2.5 Idaho and The Snake River Basin Adjudication

In Idaho, agriculture makes up a larger share of economy than other mountain States. As such, agriculture accounts for an even larger share of total water use than other prior appropriation States (15% in Idaho compared to 20% in California, Colorado, Utah). Idaho is not like States such as California and Colorado where the market value of water appears to be set by the demand in the urban sector. Idaho specialises in growing potatoes, which are the State's symbol. Aside from potatoes the other large crops grown in Idaho are Sugar beets, Corn, Alfalfa, Wheat and Barley[13]

One thing that does make Idaho unique is that 85% of its land area and 90% of its water supply lie within a single basin; The Snake River. Originating in Wyoming's Yellowstone and Grand Teton National Park, The Upper Snake River forms a crescent across the whole of southern Idaho creating the 5th most productive region of irrigated agriculture in the United States. Then it forms a deep canyon and traverses up Idaho's western border before merging with the Colombia river in Washington State. The Upper Snake River, and the Bear River Basin in Southern Eastern Idaho were first settled by the Mormons in the 1850's who built some of the first irrigation ditches which today hold some of the most senior rights. However most of the large scale irrigation in Idaho was not built till after the Carey Act (1894) which allowed farmers to form public irrigation districts to raise money for Infrastructure and the Reclamation Act (1902) which led to a handful of large dams with storage on the Snake and Boise rivers to manage flows. After the 1950's the

[11]The IDWR staff member I talked to said that most of the application fee covers this newspaper publication, and that the fee does not even come close to covering the value of the time of IDWR staff involved in the transfer

[12]Anecdotally, IDWR staff members report that these disputes are less common after adjudication, and the average water right transfer proceeds far more quickly, however I do not have any data on this.

[13]There are some smaller crops that Idaho specialises in such as peas, beans, hops however these are such a small share of total acreage that they will not play a significant role in our analysis.

technology for pumping deep groundwater wells became widely available which led to a large expansion of groundwater irrigated farmland on the Upper Snake River Plain. However depletion of this aquifer eventually led to reductions in surface water flows downstream in the lower snake river.

The origins of the Snake River Basin Adjudication lie in this reduction in surface water flows in the lower Snake as a result of groundwater pumping on the Upper Snake Plain[14]. Since the groundwater farmers arrived later, their water rights were Junior to a 1930's publicly owned Hydroelectric generators downstream at Swan Falls. In 1977 a ratepayers interest group successfully sued Idaho Power for failing to protect it's interests by not enforcing it's priority against upstream pumpers. In a 1983, the Idaho Supreme Court in a surprise ruling that water rights for the Swan Falls station had not been abandoned due to non-use, and that the Idaho Power had a public duty to protect it's water rights. As a result Idaho Power was forced to file a lawsuits against over 7,500 farmers, every upstream groundwater user in the State who's water rights were 'Junior' Swan Falls.

Not only was this politically unpopular, but it also highlighted the inadequacies of Idaho's Water Right Management as this case would involve almost every water user in the middle and upper snake river for many of whom had not had their water rights documented by the State. As a result a political solution was found where in 1987 where the State settled the Swan Falls case by paying to buy out some of the Hydro Water Rights and also called that all water rights in the Snake River Basin be adjudicated to ensure that a similar conflict would not happen again.

Over the subsequent 27 years the State of Idaho would build a whole bureaucracy to undertake the most complex water right adjudication every undertaken in the United States. Because IDWR had limited bureaucratic capacity, the adjudication was broken up into 35 sub-basins. Three teams based out of IDWR's 3 regional field offices in Boise, Idaho Falls and Twin Falls would each adjudicate one basin at a time in their local area. This differences in the timing of adjudication in otherwise nearby similar sub-basins is what is going to form the basis of my identification strategy in this paper.

In 1988 IDWR began collecting the first water rights claims as part of the Adjudication Process. In 1992 The directors reports with preliminary findings and recommendations were released for these first 3 test basins, and the teams moved onto the next set of basins. However due to litigation into the nature of water rights which was working it's way through the Idaho Supreme Court, the first Irrigation Water Rights were not officially decreed until 1999[15]. After a basin is adjudicated the judge issues a 'Partial-Decree'

[14]Stapilus and The Idaho State Bar Water Law Section (2014) gives a very detailed background how the SRBA was organised. Vonde et al. (2016) discusses all of the legal issues that arose from adjudication

[15]These issues included litigation over the constitutionality of adjudication, the conditions under which a water right is forefitted due to non-use, the meaning of Idaho water rights ensuring water use in 'Public Trust', How water connections should

announcing the water rights in that basin, and these water rights are legally binding as of the date of the decree[16]. However many smaller 'De Minimis' Domestic and Stockwater rights were decreed much earlier than this. The vast majority of the water right decrees which will make up the empirical analysis in this paper occurred between 1999 and 2013. The final unified decree of all water rights in the Snake River Basin was made in August 2014.

Although they make up a relatively small share of Idaho's water use, there are two regions of Idaho outside of the Snake River Basin, the Northern Panhandle and the Bear River Basin near Utah. Adjudication of the Northern Idaho Basins began in 2008 and is ongoing, with the first preliminary directors reports issued in 2014. The Adjudication of the Bear River is expected to begin in 2017 after the conclusion of the Northern Idaho Adjudications. '

Groundwater Management

Idaho is unusual in that it has 'Conjunctive Management' of it's groundwater supply, groundwater is managed under the same priority system as surface water. In most States the institutions which groundwater are detached from those managing surface water. Some States (such as Texas) are governed by a 'Rule of Capture' under which you are legally entitled to whatever water you pump out of the ground. In other States (such as ...) some version of the riparian doctrine which applies, implying that users of an aquifer have a right to make 'Reasonable Use' of the aquifer.

Groundwater adds yet another layer of complexity to water institutions in Idaho. In many States the institutions which manage groundwater detached from those managing surface water. In most parts of the United States Groundwater is governed by a 'Rule of Capture' under which you are legally entitled to whatever water you pump out of the ground[17]. Even in States where there is not a pure rule of capture, there is still some version of the riparian doctrine which applies, implying that users of an aquifer have a right to make 'Reasonable Use' of the aquifer[18]. The result of this is that surface water users typically substitute for groundwater during a drought (which is often free except for energy costs). This has lead to massive depletion of groundwater and subsidence in places like California's Central Valley.

Prior to the beginning of the Swan Falls dispute, Groundwater was perceived as being a more secure water source, it is not susceptible to annual fluctuations in rainfall since water can still be pumped out of the ground during a drought. However since the adjudication, Idaho has started enforcing priority on

be determined within the Snake River Basin and how Federal and Indian rights should be quantified.

[16] This was explicit Stated throughout and appears in the text of the final decree

[17] For example Texas

[18] For example California

groundwater rights. The State uses hydrological to infer which groundwater users are having . These farms can either be forced to curtail individually or form a groundwater management district and develop a mitigation plan to reduce their water use[19].

[19]Ghosh, Cobourn and Elbakidze (2014) discuses the implications of conjunctive management for water banking in Idaho

3 Data

I compile a novel combination of sources to construct an individual level panel dataset of water rights, water right trades and leases, soil characteristics, climate and production data for the State of Idaho. Starting with IDWR's comprehensive database of water rights, I merge in data on all trades and leases of water rights between 2000 and 2016 to form a panel. Using the GIS shape-files associated with each water right's 'place of use', I merge in remote sensed spatial data from USDA's Crop Data Layer, an annual remote sensed dataset of estimates of which crop is being grown on each piece of land throughout the continental USA. In order to infer whether water right trades lead to more efficient patterns of water use, I merge in spatial soil and climactic data from USDA's gSSURGO soil database and the PRISM climate database respectively[20]. Finally, I use county-level aggregate data from the Census of Agriculture to determine whether adjudication had an aggregate impact on on-farm investment and land values.

One important challenge of using these different data-sets is that each dataset has data availability for different ranges of time. The second panel in Figure 4 highlights which years data is available form each data source.

3.1 Water Right Data

Idaho's publicly available water rights database contains the universe of over 162,000 water rights[21]. Associated with each water right is information on 1.) who owns the water right, 2.) where (geographically) and how (in nature) the water can be used, 3.) how much water can be used and 4.) where the water is diverted from. There is also information about 5.) the 'priority date' when the water was first diverted, which determines the order in which rationing occurs during a drought. Finally there is data on 6.) The date on which the water right was certified either through the bureaucratic issue of a licence, or (more commonly) through legal decree after a water right adjudication.

Of the 162,000 water rights in my data: 139,000 lie within the Snake River Basin, which becomes adjudicated during the period of my data. 44,500 water rights which are reserved for agricultural use. These rights account for majority of consumptive water use in Idaho. The vast majority of the remaining rights

[20]Papers which use a similar method of constructing data to describe use of water rights include Ji and Cobourn (2017) and Leonard and Libecap (2016)

[21]This data available here: `https://research.idwr.idaho.gov/index.html#GIS-Data`

(104,000) rights are too small to be actively managed by IDWR an are used for either filling stock water ponds or domestic water supply. The rest of these water rights either allow reservoir storage (4,500) for later use[22], or they have a variety of other large water uses such as Municipal, Commercial, Power Generation Recreation, Environmental uses (4,500) rights. However 85% of water right transfers occur within the agricultural sector, and for the most part this paper will focus on just agricultural water rights.

I also have the history of water right transfers and leases from IDWR, which I merge into the water right data to form a panel of who owns what across time. In particular I observe all applications made to IDWR to modify water rights between 1999 and 2016, and whether the conditions under which those applications were approved or denied. Water rights can be modified in 4 ways: 1) change of owner, 2) change of place of use, 3) change / add point of diversion, 4) change of nature of use 5) change period of use.

The volume of water associated with a water right is not explicitly defined, rather water rights define a rate at which water may be diverted when in priority, and the seasons during which they can be diverted. When a farm transfers water, he only has the right to sell a volume of water equal to his consumptive use. Often only 10-20% of water applied to field is absorbed by the crop, the rest sinks back into the groundwater table and eventually returns to the river bed. The IDWR keeps estimates of water consumption for each specific combination of crop and irrigation technique and these define the quantity of water which is available for a transfer.

Leasing data is from Idaho's state-run Water Supply Bank (WSB). Unlike the transfer data this data may not be comprehensive. There are two ways to legally lease water rights in Idaho, either through the Water Supply Bank which is a which is a State operated intermediary who act as a clearing house for all short term water lease in the State of Idaho. Alternatively water can be leased through local 'water right rental pools' organised through local 'water masters' and irrigation districts. There are anecdotal accounts that informal water right leases outside of the purview of IDWR were common especially before adjudication, even though such arrangements are technically not legal. Lease Data - The main takeaway from the part of the analysis about leases should be that what leases highlight is that there is no perfectly efficient lease market which could account for the low level of water right trading

Table 1 contains summary statistics for the water rights in my dataset. This table has a several key takeaways: Firstly the distribution of the volume of water rights is right skewed. There is a very small number of water rights account for a large share of the volume of water. This is true both between water

[22] Depending on whether the reservoir was build by the USBR or the Army Corps of Engineers, the management of water might either be in the hands of the federal government or a local water master, typically these institutions manage this local water use.

uses and within irrigation water rights. 42% of irrigation rights have a groundwater source, however a much larger share of water right transfers involve irrigation water rights. On average a water right irrigates around 191 acres of land. Traded water rights tend to be far larger than average. Approximately 18% of irrigation water rights are ever traded. However we observe far fewer leases (only 1% of irrigation rights). 52% of water rights which are leased in the data are also traded at some point. Most water rights (82%) and Leases (92%) have been adjudicated before we observe a transaction. The median duration of a lease is 2 years.

3.2 Crop Data Layer

To infer what crops are being grown on irrigated lands in Idaho, I use data from USDA's Cropland Data Layer (CDL) dataset[23]. This dataset uses a calibrated classification algorithm to estimate land use, particularly which specific crop is being grown on each piece of land throughout the United States. The CDL dataset is at a 30x30m resolution throughout the United States. For the State of Idaho, complete data is available for the years 2005 and 2007-2015.[24] For the location of each irrigation water right, we are able to identify the percentage of land allocated to six major crops of the region: alfalfa, barley, corn, potato, sugar beet and wheat, as well as idle and non-agricultural land.

Satellite estimation is of crop choice is a noisy process. For the 10 most commonly grown crops in Idaho, Crop Data Layer estimates the crops with between 85-95% accuracy. Although this is noisy, it should be noted that a noisy y measure will typically not bias estimates. Further Crop Data Layer includes an estimate of the covariance structure between the errors and so this can be controlled for in the estimates.

Figure **??** shows how the acreage shares of each of these crops has changed over time. We will simplify much of our empirical analysis by grouping these crops into three types as follows: (1.) Water Intensive Crops include corn, sugar-beets, potatoes,and all other water intensive crops observed. (2.) Drought Resistant Crops include Wheat, Barley and Alfalfa. (3.) Fallow and Pasture includes fallow land and pasture land and other hay crops. What is clear from this figure is that there has been a significant decline in pastureland offset by modest increases in both drought resistant crops (notably Alfalfa) and water intensive crops (notably Corn and Sugar Beets).

[23] Available at https://nassgeodata.gmu.edu/CropScape/

[24] In 2005 only partial data is available but this data covers all of the major agricultural areas in the Snake River Basin.

3.3 Soil and Climate Data

Soil data is obtained from the SSURGO database, a soil database developed by USDA- NRCS. The SSURGO dataset contains a crop-specific yield estimate for each soil type, and from which we construct an average irrigated crop yield map for wheat and corn. This allows us to capture the possibility that a parcel of land is especially suitable for certain crops but not for others, which may explain some of the empirical cropping choices. We also include common soil quality indicators in our model, such as irrigated and non-irrigated soil capacity class, percent of clay, percent of slopes, and the k-factor.

Weather data is obtained from the PRISM climate dataset developed by Oregon State University, which provide small-scale climate maps and estimates. From this dataset we can get daily estimates of precipitation and temperature at a high resolution for all years of our sample.

3.4 Census of Agriculture

Finally I merge in data from the Census of Agriculture which asks detailed questions about on-farm economics variables. In particular I use data asking about the irrigated acreage of different crops, farm revenues and costs, farmland value and on-farm investment in machinery and improvements.

There are two drawbacks to using Census of Agriculture, the first is that I only have data available aggregated at the county level[25], this is particularly problematic because Idaho's counties frequently do not overlap with the basins which are used for adjudication. However we can calculate at any time the fraction of water rights in a particular county that have been adjudicated. Secondly the Census of Agriculture is only available every 5 years with the most recent being in 2012. As a result we only really have 3 observations with significant numbers of agricultural water rights having been adjudicated.

[25] I hope in the future to be able to access Census of Agriculture micro-data and micro-data from other USDA Irrigation Surveys.

4 Empirical Strategy

4.1 Reduced Form Panel Estimation

I use variation in the timing of when water rights become adjudicated to infer the impact of adjudication on economic outcomes. As previously discussed this is done using an parcel-level panel, by merging individual water rights with data each year between 2000-2016 on what crops are being grown on the parcel of land associated with each water right and with transaction data on whether their water rights were leased, changed or sold in a given year. The unit of observation is an individual parcel of land owning one or more water rights[26]

Let y_{it} be the outcome variable of interest for a parcel of land i in year t. This might be whether or not a farmer is growing a particular crop or whether a water right was traded in a particular year.

We are interested in estimating the impact of D_{it}, which measures whether the water right attached to that plot of land had been legally adjudicated in year t. I will suggest several specifications:

Firstly, the simplest way we might specify this would be to have fixed effect for each plot of land γ_i as well as a time fixed effect γ_t. In this specification we are basically learning about the impacts of adjudication by comparing the relative change in a parcel of land whose water right that got adjudicated at a particular point in time to another who did not.

$$y_{it} = \alpha_0 + \alpha_1 D_{i,t} + \gamma_i + \gamma_t + \varepsilon_{it}$$

The identifying assumption in this model is that

$$\mathbb{E}(\varepsilon_{i,t} | D_{i,t} + \gamma_i, \gamma_t) = 0$$

This assumption would be violated if there was something unobserved about the nature of a water rights which caused it to be adjudicated sooner or later. This assumption might be violated if variations in the timing of adjudication either within or between basin are correlated with unobserved factors affecting water

[26]On parcels of land where multiple water rights are held of different sizes (for example some rights are held by an irrigation district and others are held by an irrigation district whilst others are individually held, I take the intersection of these water rights as the unit of observation. The treatment variable is then the share of water rights adjudicated. I also include pieces of land that have previously held water rights but no longer do. Pieces of land which could potentially be irrigated but never, are currently excluded from my data set, however I plan on including them in future versions of this paper.

right trading, or farm productivity and crop choices.

Firstly, within a basin some water rights are decreed before others. Typically most of the water rights are decreed about a year after the initial basin report is released, however some rights might have some ongoing disputes which can lead them to be decreed late. If this is the case then we might worry that if the most productive land or water rights are most likely to be disputed then there is some endogeneity here. To remove this concern we can use the earliest adjudication data of water rights in a particular sub-basin as the adjudication date for that entire sub-basin.

Secondly, most of the variation in timing in the date at which water rights are decreed depends on when the adjudication for that particular basin began and finished. In order to believe that our estimates are causal we need to believe that the order in which the basins were adjudicated was uncorrelated with some unobserved characteristics of the basins.

To understand this it might help to understand the background behind the order in which basins got adjudicated[27].

The first 3 basins IDWR selected for adjudicating were very intentionally chosen (57,43,13) on the basis that they were thought to have the complex issues that would be most challenging to adjudicate. The reasoning was that if you could adjudicate these complex basins first, then the necessary case law would develop which would make all subsequent adjudications more straightforward. These first 3 adjudications took over a decade to complete however subsequent adjudications proceeded much more quickly. After the first three adjudications, the remaining basins were divided among the three adjudicating teams based on proximity to their offices and adjudicated sequentially. Because of the is considerable variation in the timing of adjudication among neighbouring sub-basins.

Ideally I would like to claim that this variation is random, based on Stapilus and The Idaho State Bar Water Law Section (2014) after the first 3 basins, the order of adjudication was arbitrary but the directors of adjudications might have had some discretion as to the exact order. We can observe whether farms in basins that we adjudicated earlier rather than later have different characteristics. Table 2 shows that unfortunately there are significant differences in the characteristics of farms adjudicated earlier rather than later. Although this is not a problem per sey since we can control for this heterogeneity in our regression. It does suggest that timing of adjudication is not quasi-random.

Figures 3 and 4 show the timing of adjudication of basins and the heterogeneity therein.

[27]This is based on Stapilus and The Idaho State Bar Water Law Section (2014) which gives a very detailed oral account of the adjudication from the perspective of IDWR and it discusses all their motivations for the particular order in which they were adjudicated

The advantage of using the panel approach described above is it very cleanly identifies the impact of an adjudication, however the disadvantage of using the panel approach described above is that it will strip out the impacts of adjudication which do not act entirely through the relative timing of water right adjudication. For example, many of the benefits of adjudication might have come through advances in water case law in the Idaho Courts, or from changes in how water rights are measured, accounted and monitored or in changes in how IDWR process applications for water right transfers. All of these changes might have affected all water users in Idaho simultaneously. As a result they will not be captured in the panel approach above. To attempt to estimate these things I also include specifications which have a parametric time trend and try to control for other time specific factors. The parametric time trend I will use will typically be a polynomial in calendar year. The other factors I will control for are climate (average temperature, growing degree days and precipitation as measured in PRISM) and crop prices indices and farm cost indices (either from the USDA or from FRED). Using this approach we hope to estimate a more holistic impact of adjudication, if through somewhat less credible methods. Typically our estimates using parametric trends are larger than those without suggesting that we are capturing some additional effect.

5 Results

This results section proceeds as follows: Firstly, I establish that after adjudication there is an increase in the rate at which water rights are traded. This effect is concentrated in irrigation and particularly groundwater rights. The effect is not statistically significant for short term leases. Secondly, I show that trades and lease of water rights on average move water from lower to higher quality parcels of land as measured by the soil and climate characteristics of each parcel. Thirdly, I show that after adjudication buyers of water start growing more crops, and more valuable crops, whilst sellers of water do not make major changes in their production patterns. Thus trades of water rights create economic gains and adjudication leads to more trades. Finally, using county-level Census of Agriculture data I test where there is any measurable aggregate impact of adjudication on farm profits, irrigation and on-farm investment in machinery after adjudication, however I fail to find any significant impact of adjudication on these outcomes.

5.1 Impact of Adjudication on Water Right Transfers and Leases

Figure **??** is an event study figure, it shows the coefficients of an OLS regression of a dummy variable measuring whether or not a water right was traded in a particular year on a set of dummy variables representing how many years before or after the right was formally adjudicated by a court. This regression controls for time-specific effects with year dummies, and for differences in the propensity of different farms to buy or sell water rights with farm specific fixed effects. The standard errors are clustering two ways at the adjudication sub-basin and year levels. This conservative approach accounts for the fact that our identifying instrument (Adjudications by the State of Idaho) varies on a basin-by-basin basis and for the fact that there might be common factors affecting the productivity of farms within each basin or each year.

This figure has two key takeaways: Firstly water rights are traded at a persistently higher rate post-adjudication compared to before. This is consistent with adjudication reducing transaction costs. The estimate change in the coefficients β post-adjudication compared to before is around 0.01. Interpreting this as a linear probability implies that a water right is around 1% more likely to be traded every year post-adjudication 1%[28]. Although standard error bands overlap, there is a distinct change in level after compared to before and the results are statistically significant when pooled. Secondly, it appears that about half of

[28] Although this might be theoretically problematic (for example predicting negative probabilities), results are equivalent using a logit or probit regression

the treatment effect occurs at $t-1$, the year before adjudication. This might occur because about a year before water rights are officially decreed by a judge as having been 'Adjudicated', The adjudicators release a preliminary sub-basin report which details it's proposed allocation of water rights in the basin. Although any water user in the basin has the right to dispute an adjudication, the vast majority of preliminary findings are not disputed and are eventually confirmed as water rights[29]. So the jump in transfers we observe in $t-1$ might be because much of the uncertainty is actually resolved with the release of sub-basin reports before the final adjudication is made officially decreed.

To formalise the results discussed above, Table presents 6 regressions which estimate the change in the rate at which water rights are traded post-adjudication. The first three columns estimate the change in the only on irrigation water rights while the second three columns estimate the change in rate for all water rights (irrigation and non-irrigation) in the State. I present three different specifications the first contains only individual fixed effects but does not account for time trends, the second regression attempts to account for time trends with parametric controls (specifically crop prices, quadratic time trends and climate variables), the third regression is a panel 'within' estimate which accounts for time trends non-parametrically.

Although the third regression gives the preferred estimate, a coefficient of 0.010 (s.e 0.003) consistent with our discussion above. Given our preferred estimate of $\beta = 0.01$ this would imply that the rate at which water rights are traded increases by 140% from a baseline of 0.7% of all water rights being traded each year to 1.7% of all water rights. Note that although only a small percentage of water rights change hands every year, over time this compounds such that 18% of water rights are traded between 1999 and 2016.

One concern with the conservative approach of removing all time specific fixed effects is that it might not capture some aspects of Idaho's adjudication which affected all water rights holders simultaneously outside of basin-specific adjudications. For example during the period of this data the decisions of Idaho developed substantial case law about the extent and definition of water rights and the conditions under which transfers can take place[30]. Because these decisions affected everyone in the basin simultaneously they are not captured in our estimate with time fixed-effects. But arguably these effects reflect as much of the benefits of adjudication as the reduced ambiguity when a particular basin's rights were signed off on. This dynamic is reflected in the fact that we find substantially larger estimates in our regressions without time fixed effects (0.019 and 0.017 in our models with no time trends and parametric time trends respectively).

[29]Note to self - ask IDWR how many water rights were disputed after preliminary reports were released.

[30]Vonde et al. (2016) has an extensive discussion of all of the Basin-wide Idaho Court rulings relating in the Snake River Basin Adjudication which developed substantial case law about how water was to be managed affecting all water users simultaneously. Issues included: what volume of rights can be transferred, when adversely effected third-parties can object to a transfer, the conditions under which a right is forfeited for non-use and whether private parties can own in-stream water rights, how storage is administered and many, many more things.

Next figure **??** tries to break out the heterogeneity in the patterns of water right trades. The first panel shows that almost all of the increase in water right transfers after adjudication comes from Irrigation Water Right. The second panel shows that a large share of the increase in water right trades post adjudication comes from water rights that are sourced from groundwater. Whilst the third panel shows that most of the increase in water right trades comes from water rights with priority dates between 1950-1975. This is the beginning of the era of irrigated agriculture in the United States. Table 4 confirms the results found above with pooled regressions.

I conduct a similar analysis for the lease data. Although I find an effect of a similar magnitude, because there are very few observations and there insufficient data to draw a credible conclusion. However the main story with the leases should indeed be that there is so few of them. We might expect that leases would have fewer bureaucratic checks because they are temporary in nature, however the fix cost paid in the legal process of assessing leases is higher relative to the total value of the water.

The small number of leases in our data is reassuring because it tells us that the transfers of water rights do likely lead to more efficient water use. If we imagine a hypothetical world with a perfectly liquid market for water right leases, then in this world the true pattern of ownership of water rights is immaterial to the efficiency of water use because the water can be leased by whomever has the most efficient use for it at any point in time.

5.2 Soil Characteristics

In this section I look at the soil and climate characteristics of plots of land who buy and sell water rights. I claim that transfers of water rights moves water from relatively less productive pieces of land to those which are more productive.[31]

Table **??** shows the differences in the average characteristics of of the buyers of water rights and the sellers. Note that the average difference in the characteristics of pieces of land is systematically different between buyers and sellers of water rights that is suggestive of water right transfers systematically moving water to be user on more valuable pieces of land. Although these results are small, it is important to note that because it is challenging moving water long distances that most of the water right transfers are local (97% are within water basin). Where the differences in the average soil characteristics are all ready small, so the fact that we find a statistically significant difference is indicative.

On average the buyers of water rights live on parcels of land which are warmer and have higher average

[31] In the future I hope to estimate an econometric model to calculate the value added from each of these characteristics more rigorously.

precipitation. They have a lower elevation, implying that on average water rights move water downstream (they are less likely to be 3rd party objections selling water rights downstream rather than upstream. On the other hand if before adjudication upstream water users could unlawfully steal water and deprive downstream users of a source. Then we might expect that at after adjudication there might bne some simply paper trades of water rights to restore the allocation of water to what it was previously. Buyers of water rights have a higher k-factor (and so are more resistant to erosion) and a higher clay percentage. The land is flatter, has more frost free days.

I use the USDA has estimates of the agricultural potential of each parcel of land in the US. Merging this data with the average price of different crops in the base year, we can estimate the average expected per acre revenue for each parcel of land. Under this expected revenue measure we find that the parcels of land who buy water rights are more productive in the domain of irrigated agriculture by on average $34 per Acre. We find that the sellers are just as productive at non-irrigated agriculture as the buyers. This means that water right transactions are moving water from parcels of land who have comparative advantage in irrigated agriculture to parcels of land who have comparative advantage in non-irrigated agriculture.

5.3 Impact of Water Right Adjudication on Crop Choice

In Idaho there are eight major crops grown: Corn, Potatoes, Alfalfa, Sugar beets, Wheat and Barley, Pasture, [32]. In addition to this there is a large quantity of idle cropland and unimproved land.

Table 7 shows how the shares of the 9 most widely grown crops in Idaho change after adjudication. Although there appears to be some evidence of a decline in the share of Pastureland by 2 percentage points and of Sugar beets by half a percentage point. It is not clear that these are economically significant.

To simplify our empirical analysis we will group the crops into three classes: High value-added buy water intensive crops include Corn, Potatoes, Sugar beets and speciality crops (for the most part the results are similar if you dis-aggregate the estimation by crop). Medium value but drought resistant crops include Wheat, Barley and Alfalfa[33]. The third category describes Idle land or land which is only growing non-irrigated pasture [34].

Table 6 shows how these three categories of crops changed after adjudication. Although we again see a

[32] Plus a variety of high value added speciality crops (Beans, Peas, Hops, Apples Peaches) whose market shares are too small to mesure in this exercise

[33] Calling Alfalfa a drought resistant crop is somewhat misleading. Alfalfa is a very water intensive crop, however it is also a crop which will not wither if it is water supply is cut off, as a result it is a good hedge crop for someone who has an uncertain water supply. For this reason we classify it with

[34] This type of simplification is common in the agricultural economics literature for example Hornbeck (2010),Griffin and Anchukaitis (2014)

two percentage point decline in Pasture land, possibly offset by an increase in crops the empirical evidence is not very strong.

However what we can do is instead of looking at the impact of adjudication, we can look at the impact of transfers in water rights. Although the previous sections found evidence of transfers of paper water rights, this might not necessarily imply changes in actually patterns of water use if outside of the jurisdiction of IDWR local institutions were reallocating water within basins. To find evidence of concrete changes in water use arising from adjudication and water rights transfers we will examine how water rights transfers change the patterns of water right use.

In Table 6. After a water right transfer, we find the share of drought resistant crops increases by 5 percentage points, these crops are likely converted from pastureland which decreases by 5 percentage points. There is no change in the acreage of water intensive crops. This raises an interesting question: Why is the buyer of these water rights choosing to grow lower value, but drought resistant crops rather than high value added water intensive crops. Perhaps it has something to do with the fact that this increase in acreage is largely driven by groundwater users.

On the other side of the coin, sellers of drought resistant crops might slightly decrease their acreage of drought resistant crops (perhaps by around 1 percentage point). But this is not enough to offset the increase in acreage from water right buyers.

These results suggest a small but significant increase in output as a result of water right trades and since adjudication leads to an increase in these trades, there is an economic benefit from adjudication. However it is still unclear how large these benefits form adjudication are, quantifying these will be the subject of my future work, where I plan to estimate crop choice and water right transaction with a multinomial crop choice and matching model which will allow me to estimate the surplus gained from adjudication.

However, for now the next section will describe some suggestive evidence of the aggregate benefits of adjudication from Census of Agriculture data.

5.4 Census Data - Impact of Adjudication on Farm Investment, Profits and Land Value

This section links adjudications to aggregated county-level Census of Agriculture data. It should be noted that because the Census of Agriculture is so infrequent and does not overlap precisely with our 'sub-basin' treatment areas, the results are under-powered statistically and are sensitive to specification. Using this data we hope to answer three questions:

The first is how adjudication affects crop choice and aggregate acreage. To a large extent this is dealt with in the previous sections, however it is reassuring if these results can be replicated with a dataset that has a completely different time horizon. Table 9 estimates how acreage changes after adjudication and finds an increase in the share of irrigated acreage, largely as a result of a decline in the acreage of non-irrigated crops and pasture. This is consistent with our previous findings.

The next two questions relate to how adjudication affects aggregate economic outcomes, which are captured in the regressions in Table 9.

The first is whether any increase in the productivity of water use as a result of adjudication becomes capitalised in land values. Typically water rights are sold with the land on which they are used. If adjudication increases the value of the water, which through complementary also increases the productivity of the land then we might expect the value of agricultural land to increase. This is examined in the first two columns of Table 9. Unfortunately results are mixed, having different signs depending on specification.

The second hypothesis is that if we expect that the adjudication of water rights leads to a reduction in future uncertainty about an individuals water claims, then we might expect that this leads to either an increase in on-farm investments such as investment in farm machinery or buildings and improvements on farmland. The second two columns of Table 9 test this hypothesis. I find that adjudication seems to have had a significant effect, increasing on-farm investment by almost 20%. It is not clear whether this is working through the reduction uncertainty channel I described, or through some other mechanism.

The final two columns of Table 9 test whether adjudication has any impact on net cash income. Adjudication has an extremely large and significant effect on this outcome, depending on the specification almost doubling net cash income. Although I find this effect to be subjectively implausibly large (with nosily estimated parameters you are more likely to find a statistically effect with extreme realisations), however it is suggestive of the fact that adjudication has real economic impacts.

Figures

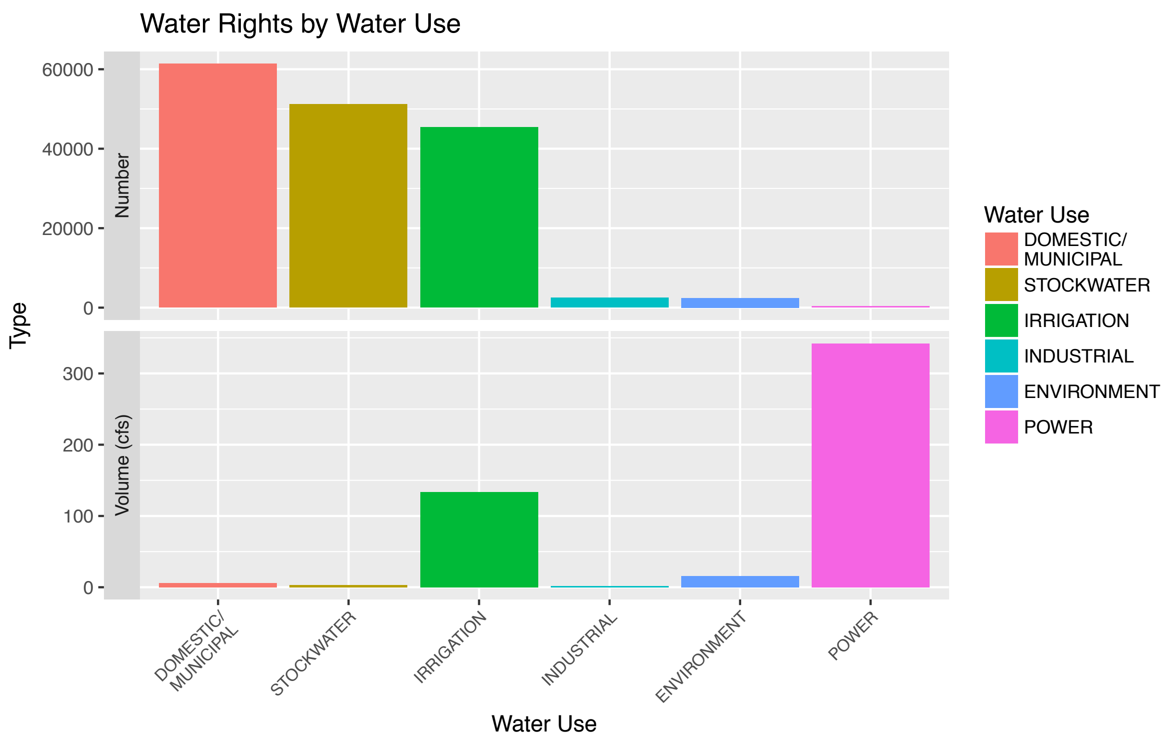


Figure 1: This figure shows the number and volumr of water rights within the state broken down by Water Use. The Volume is actually measured as a flow rate, in cubic feet per second, which implicitly defines a volume for agriculture by multiplying by the duration of the irrigation season.

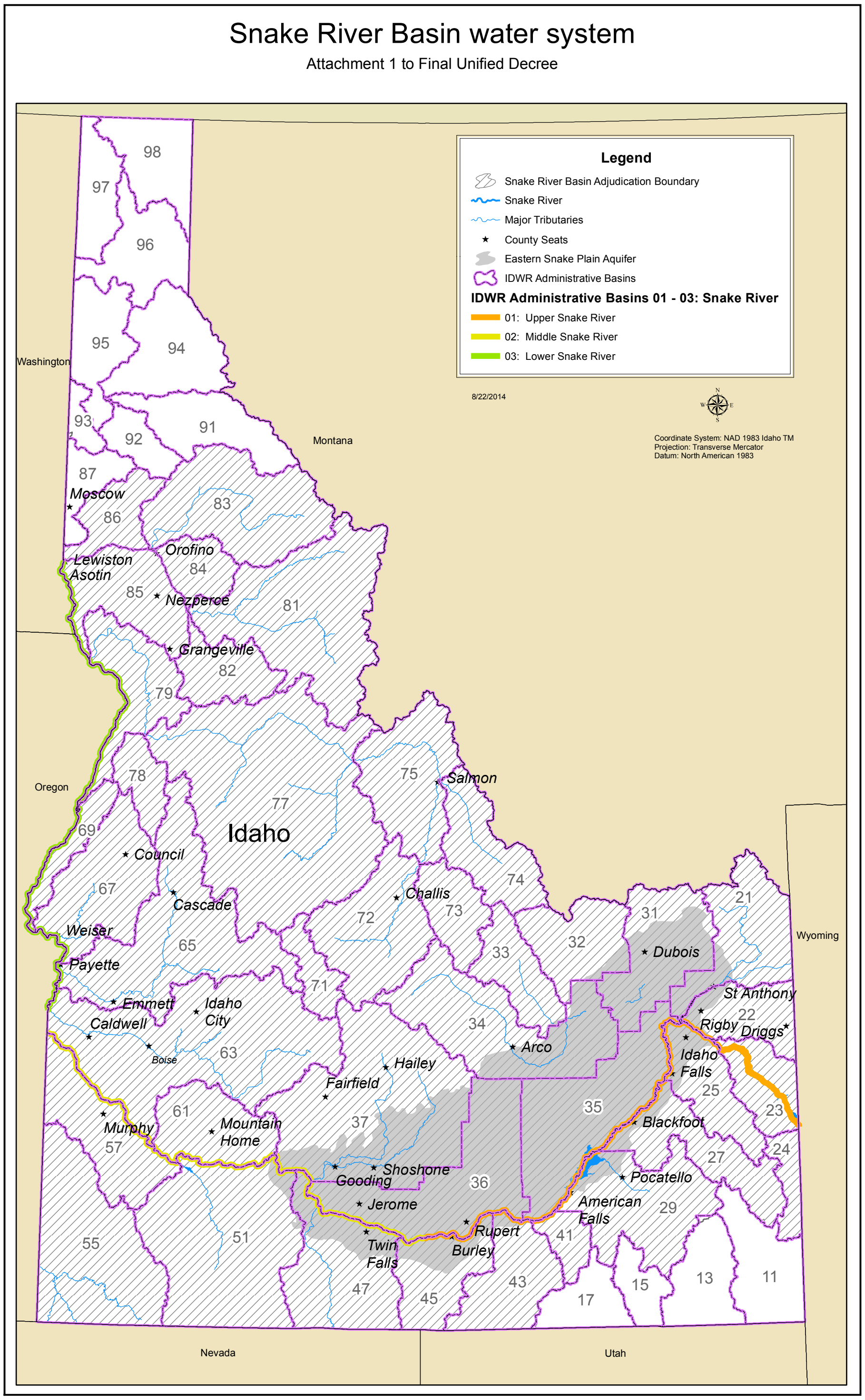
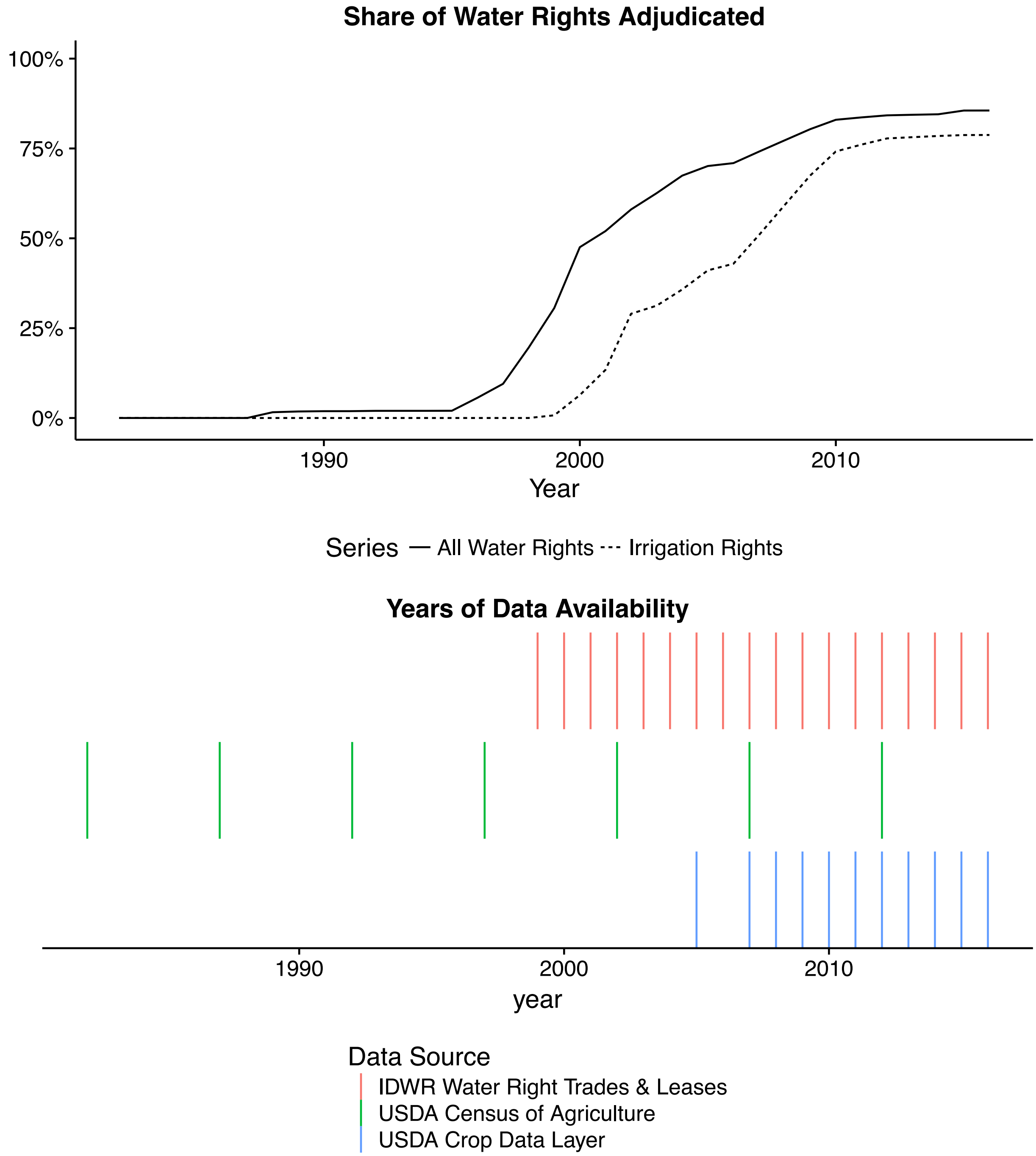


Figure 2: Source: Snake River Basin Adjudication Final Decree.
This figure shows Idaho's administrative sub-basins, the unit at which adjudications took place. It shows which sub-basins are within the Snake River Basin Adjudication and it also shows the location of the Eastern Snake Plain Aquifer, which is the source of much the State's groundwater irrigation and water right conflict.

Figure 3: Mapping of the progress of rights adjudications

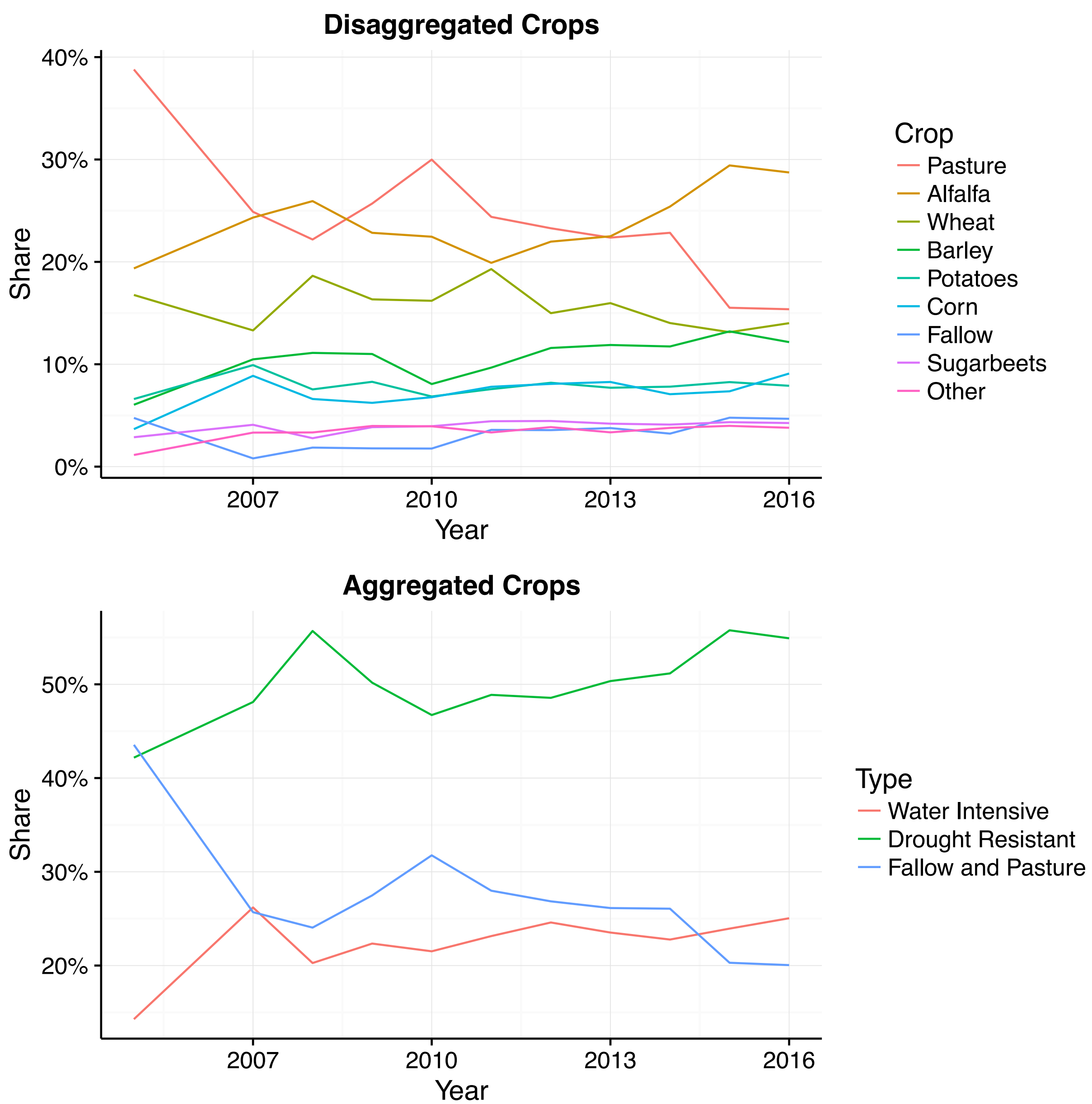
This figure shows the progress of the Snake River Basin Adjudication. The colorscale of each figure shows the share of water rights within that county which had been adjudicated by that year. Water Rights are largely unadjudicated in 1992. The spatial variation in the patterns of adjudication is what identifies my estimates in this paper. By 2012 almost all Water Rights in the Snake River Basin are adjudicated. By 2016 some additional water rights in the Northern Panhandle have been adjudicated.

Figure 4: Adjudication Progress



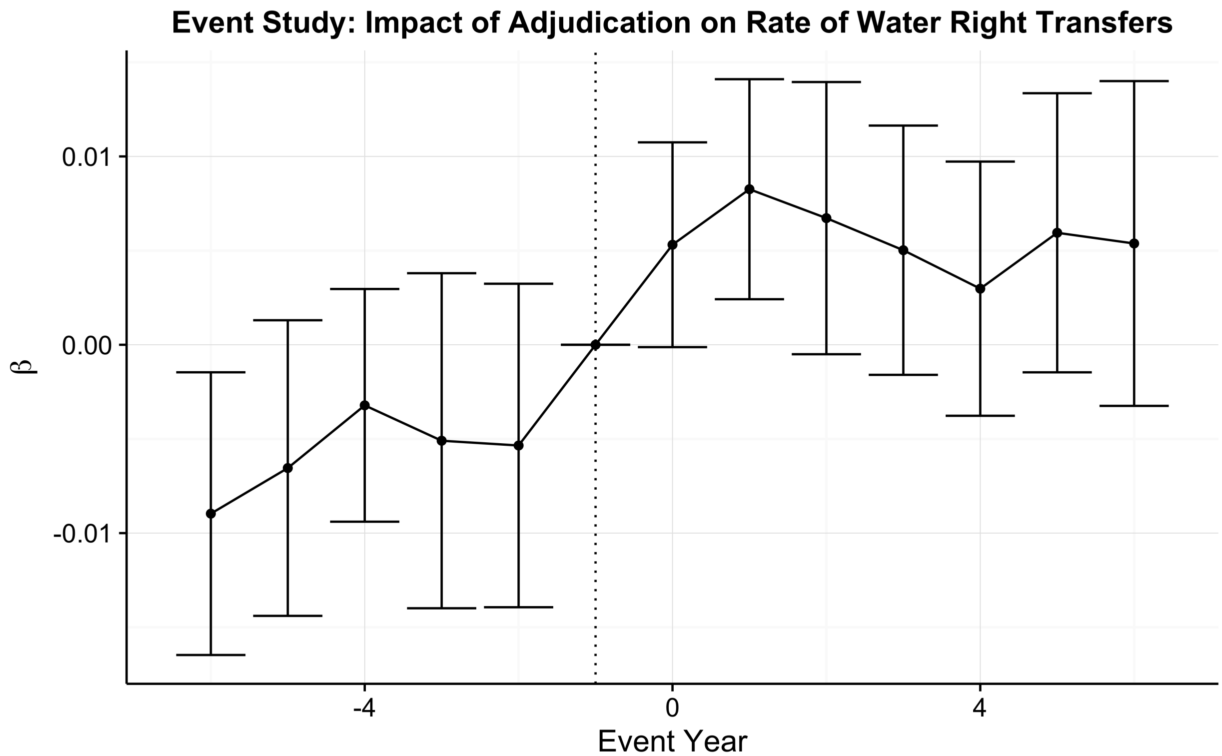
The top panel shows the progress of the adjudication as the share of water rights adjudicate increases over time from 0% to 80%. (0% is a somewhat arbitrary baseline, since I did not counted historic adjudications before 1980 in the calculation, most of these historic adjudications were superseded by the SRBA). In the second panel the lines indicate data availability. Transaction Data becomes available in 1999, USDA Crop Data Layer satellite data only becomes available in 2005. Census Data is only observed every 5 years from 1982-2012.

Figure 5: Acreage Share of Crops Grown in Idaho in Irrigated Areas



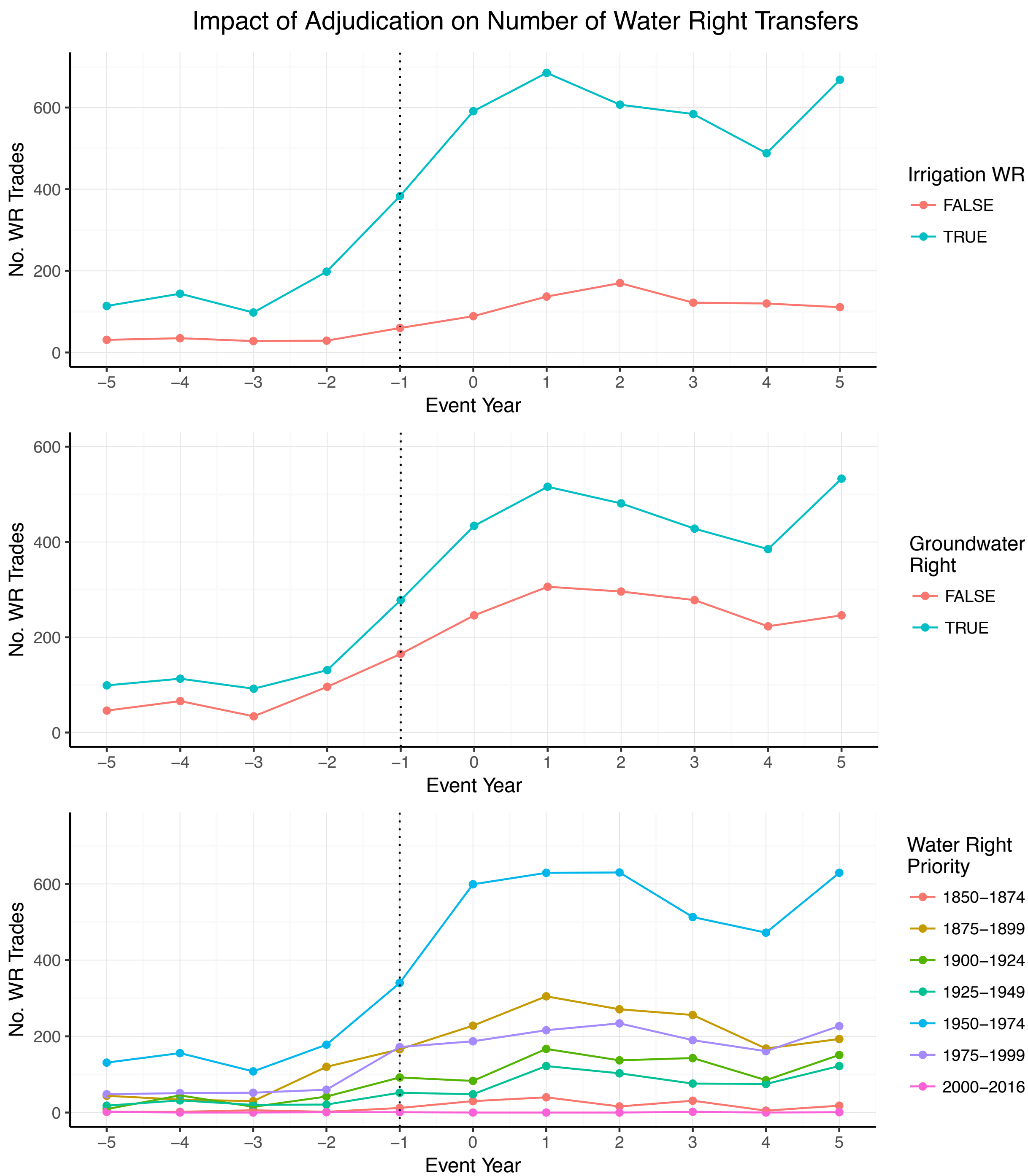
This figure shows the crop shares for each crop, but only within the shapes defined for irrigation water by IDWR. Note that the values in 2005 are biased because they do not cover northern Idaho. The second panel shows these crops aggregated into three groups as follows:
(a.) Drought Resistant Crops include Wheat, Barley and Alfalfa. (b.) Fallow and Pasture includes fallow land and pasture land and other hay crops. (c.) Water Intensive Crops include corn, sugar-beets, potatoes,and all other water intensive crops observed.

Figure 6: Event Study - Impact of Adjudication on the Rate of Water Right Permanent Transfers



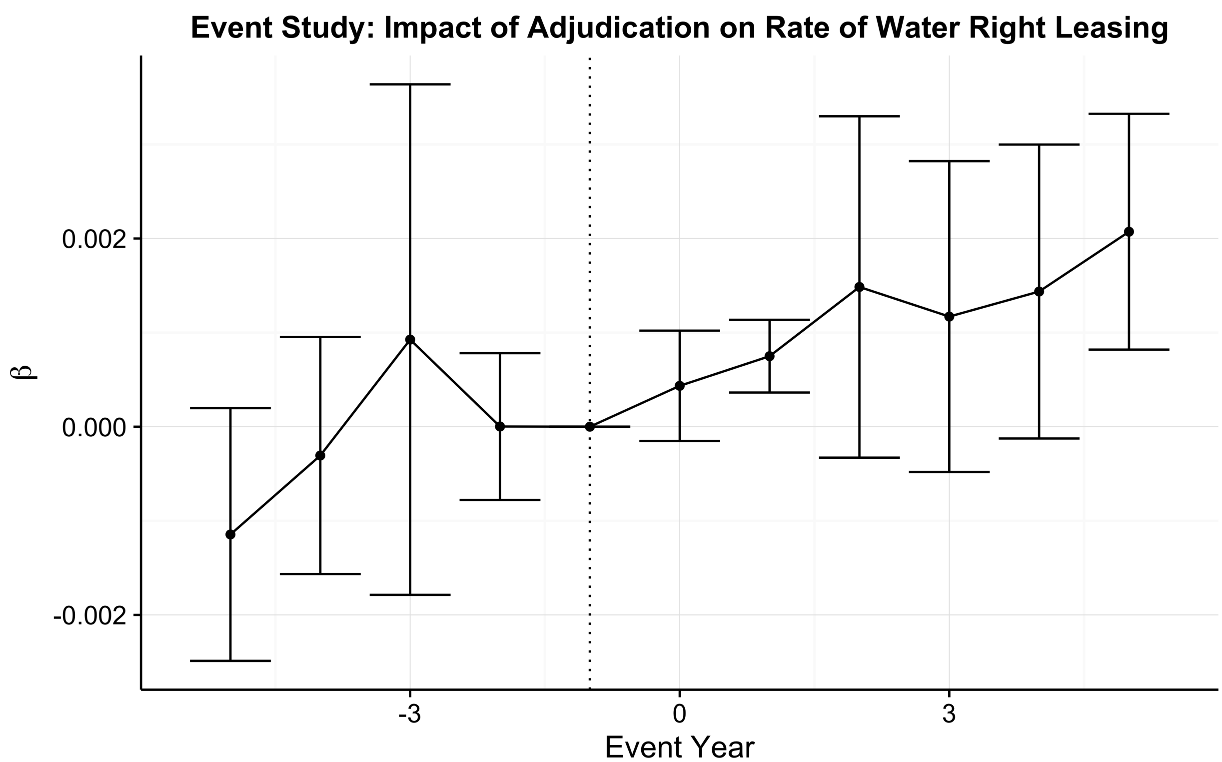
Note: This is an event study figure, It shows estimates of how the rate of water right transfers changes around the date at which the right is adjudicated. Note that the sample is restricted to only include data with at least 6 years of observations before and after adjudication. The omitted factor in the regression is -1 the year before the water right is officially decreed by a judge. The estimating equation is: $y_{it} = \beta_t \text{Years After Adjudication}_{it} + \gamma_{\text{year}} + \gamma_{\text{water right}} + \varepsilon_{it}$. Robust Standard Errors are clustered at the Basin $\times$ Year level. Confidence intervals are at the 95% level

Figure 7: Event Study - Impact of Adjudication on the Rate of Water Right Permanent Transfers

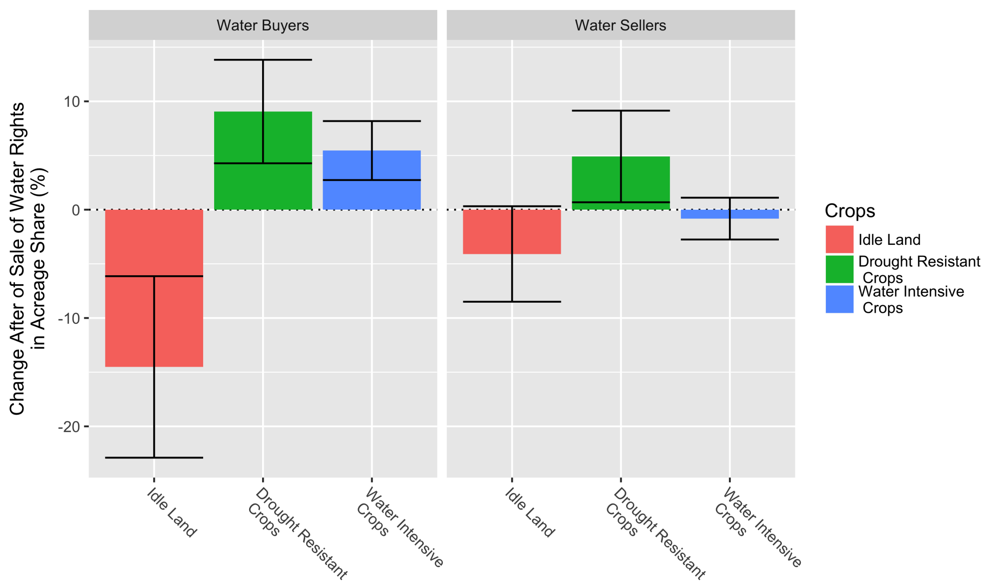


Note: This is figure shows the raw number of water rights transfers every year broken down by the whether the water right is used in irrigation, whether the water right has a groundwater source and what the priority date of the water right is.

Figure 8: Event Study - Impact of Adjudication on the Rate of Water Right Leasing



Note: This is an event study figure, It shows estimates of how the rate of water right transfers changes around the date at which the right is adjudicated. Note that the sample is restricted to only include data with at least 6 years of observations before and after adjudication. The omitted factor in the regression is -1 the year before the water right is officially decreed by a judge. The estimating equation is: $y_{it} = \beta_t \text{Years After Adjudication}_{it} + \gamma_{\text{year}} + \gamma_{\text{water right}} + \varepsilon_{it}$. Robust Standard Errors are clustered at the Basin $\times$ Year level. Confidence intervals are at the 95% level



These estimates are constructed by ruining a multinomial logit model : $Crop_{it} = \beta_{buy} After\ Bought\ WR_{it} + \beta_{sell} After\ Sold\ Water\ Right_{it} + \gamma_{year} + \gamma_{\text{water right}} + \varepsilon_{it}$. Standard Errors are clustered at the Basin × Year level. For land which bough and sold water rights predicted Acreage is calculated based on the model in 2016 with the After Bought and After Sold Coefficients turned on and off. Confidence intervals are 95% Crop Definitions are aggregated from CDL classifications: 'Idle Land' is either classified by CDL as 'Idle' or growing 'Pasture'. 'Drought Resistant Crops': include Wheat, Barley and Alfalfa. 'Water Intensive Crops' includes Corn, Potatoes, Sugar beet and All Other high value crops.

Tables

Table 1: Summary Statistics for IDWR Water Right Database and Water Right Transaction Data

	Water Rights		Transaction Data	
	All Rights	Irrigation Rights	Traded Rights	Leased Rights
Observations	163,259	46,838	2,4938	1796
Median Priority Date	1952	1952	1959	1964
Median Adjudication Date	2000	2007	2002	2003
Groundwater	54%	42%	67%	71%
Irrigation	27%	100%	87%	100%
In Snake River Basin	92%	89%	97%	99%
Adjudicated Before 2015	87%	82%	93%	93%
Median Volume (cfs)	0.04	0.49	0.99	1.60
Max Acres Permitted to Irrigate		191	479	160
Irrigable Area		659	1004	1148
Water Right Ever Traded	06%	18%	100%	52%
Water Right Ever Leased	0.1%	1%	3%	100%
Median Year of Transaction			2009	2013
Adjudicated Before Transaction			82%	92%
Median Lease Duration (Years)				2.0

This table shows various summary statistics of all water rights in the IDWR database. The table includes all water rights in Idaho, both those in adjudicated Basins and in un-adjudicated Basins. There may be omitted water rights in basins where adjudication is not complete yet. Priority Date denotes when the water was first diverted creating a water right, it determines the order of rationing in shortages. Adjudication date is the date on which the water right was adjudicated. Un-adjudicated rights are imputed in calculation of median as $+\infty$. Groundwater and Irrigation denote the share of rights with either a groundwater source or whose primary use is irrigation respectively. In the Snake River Basin is a Dummy which is TRUE if the water right is in one of the Snake River Adjudication Sub-basins. Adjudicated before 2015 is a dummy which is TRUE if it was adjudicated before 2015, this is the date when Snake River Basin Adjudication was announced complete, and is largely consists of Adjudications in the Snake River Basin. (Northern Adjudications began being decreed in 2015). Mean Volume is actually measured as a flow rate in cubic feet per second which the right holder may divert during the defined irrigation season, when the water right is in priority. This is the volume which is most consistently quantified across all water rights. Max Acres Permitted to Irrigate is the maximum area the water is permitted to irrigate at any one time. This is generally smaller than the Irrigable Area in the shape-file on which the irrigator is permitted to use the water. Median Year of Transaction is the median year in which a water right trade or lease takes place and is calculated on the subset of transacted water rights. Adjudicated Before Transaction measures whether the water right had been adjudicated as part of the Snake River Basin Adjudication at the time when the transaction took place.

Table 2: Characteristics of Water Rights broken down by timing of Adjudication

Adjudication Date	1990-2000	2001-2005	2005-2008	2009-2017	Unadjudicated
Number of Observations	3021	15626	8083	7532	10084
Groundwater Source (%)	35	55	21	33	45
Priority Date	1935	1940	1923	1931	1960
Irrigation Value Added ($)	709	1048	977	1022	733
Number of Water Sources	1.05	1.02	1.02	1.04	1.03
Large Place of Use (%)	4.7	3.2	6.8	8.8	8.0
Acres permitted to Irrigate	32	72	61	98	139
Maximum Flow Rate (cfs)	1.65	1.90	2.50	3.65	4.66
Elevation (m)	1435	1382	1362	1350	1209
Avg Air Temp (°C)	6.7	7.6	7.3	7.7	7.5
Avg Annual Precip (mm)	337	297	346	299	449

This table contains the average characteristic of different water rights and the land they irrigate, broken down by the date on which they were adjudicated. If we wanted to claim that these characteristics were quasi-randomly assigned then we would expect them to be similar across time. Unfortunately this does not appear to be is not the case. Reported Water Right Characteristics are those belonging to the water right at the end of the sample. The soil characteristics are from a single cross seciton of gSSURGO. The climate characteristics are from PRISM and are averages over the previous 50 years. Water Rights un-adjudicated as of the end of 2017 are by definition outside of the Snake River Basin, either in Northern Idaho or in the Near River Basin.

Table 3: Impact of Water Right Adjudication on Rates of Water Right Transfer

	Dependent variable:			
	Water Right Transfer Dummy			
	(1)	(2)	(3)	(4)
Post Adjudication	0.019***	0.012***	0.010***	0.010***
	(0.007)	(0.004)	(0.003)	(0.003)
Sample	Irrigation Only	All Water Rights	Irrigation Only	All Water Rights
Time FE	No	No	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes
T	21	21	21	21
N	44,353	162,587	44353	162,587
Observations	754,001	2,763,979	2,763,979	754,001

Note: *p<0.1; **p<0.05; ***p<0.01

This regression estimates the change in the linear probability that a water right is transferred in a particular year after that water right is adjudicated. In the first two columns the estimating equation is $y_{it} = \beta \text{After Adjudication}_{it} + \gamma_i + \varepsilon_{it}$, there are no time fixed effects or trends, thus attributing all secular changes in water right trading to adjudication. In the second two columns the estimating equation is $y_{it} = \beta \text{After Adjudication}_{it} + \gamma_i + \gamma_t + \varepsilon_{it}$, including year fixed effects strips secular trends in the rate of transfer out of the data. The unit of observation in this regression is the water right. robust standard errors are clustered two ways at the sub-basin by year level.

Table 4: Impact of Water Right Adjudication - Interacted Specifications

	Water Right Transferred			
Post Adjudication	0.00157	0.00640**	0.00622**	-0.00206
	(0.000983)	(0.00216)	(0.00203)	(0.00196)
Post Adjudication × Irrigation WR	0.0155*			0.0150*
	(0.00575)			(0.00540)
Post Adjudication × Junior Right		0.00904*		0.000270
		(0.00416)		(0.00161)
Post Adjudication × Groundwater Source			0.0122*	0.0114*
			(0.00513)	(0.00448)
Year FE	X	X	X	X
Water Right FE	X	X	X	X
Observations	2768586	2768246	2768586	2768246
R^2	0.090	0.089	0.090	0.090

Two-Way Cluster Robust Standard errors in parentheses. Clustered at the Basin and Year level.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

This regression interacts the change in the linear probability that a water right is transferred after adjudication with various characteristics of each water right, specifically whether the water right is used in irrigation, whether it is relatively 'junior' (defined as having a priority before 1950) and whether the water right has a groundwater source. The estimating equation is $y_{it} = \beta_1 \text{After Adjudication}_{it} + \beta_2 \text{After Adjudication} \times \text{Characteristics} + \gamma_i + \gamma_t + \varepsilon_{it}$. The unit of observation in this regression is the water right. robust standard errors are clustered two ways at the sub-basin by year level.

Table 5: Differences in soil and climate characteristics between buyers and sellers of water rights.

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Outcome	Difference	C.I
Average Annual Air Temp	0.0753	(0.0169,0.134)
Average Annual Precipitation	0.459	(-1.11,2.02)
Elevation	-7.43	(-13.8,-1.08)
K-factor	.085	(0.0215,0.149)
Clay Percentage	3.25	(2.19,4.28)
Frost Free Days	1.06	(0.515,1.61)
Land Slope	0.0564	(-0.274,0.387)
K-factor	.085	(0.0215,0.149)
Clay Percentage	3.25	(2.19,4.28)
Expected Rev/Acre Irrigated	34.2	(4.98,63.4)
Expected Rev/Acre Non-Irrigated	-2.05	(-5.39,1.29)
Expected ValueAdded/Acre by Irrigation	34.6	(5.68,63.6)

This table shows the acreage weighted average differences for each water right transaction between the soil characteristics of the water right buyer and seller. Soil quality data is from the USGS. Confidence Interval is from a one-sided paired t-test of hypothesis that the difference is equal to zero. Expected Revenue is calculated from the USGS Soil Productivity Estimates for that parcel's most productive crop multiplied by that years market price.

Table 6: Impact of Adjudication on Farm Level Crop Choice

	Dependent variable: Acreage Share of Each Crop								
	Pasture	Alfalfa	Wheat	Barley	Potatoes	Corn	Fallow	Sugarbeets	Other
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
After Adjudication	-0.020^{**}	-0.007	0.002	0.014	0.002^{**}	0.010^{*}	0.001	-0.005^{***}	0.003
	(0.008)	(0.009)	(0.005)	(0.010)	(0.001)	(0.005)	(0.005)	(0.002)	(0.003)
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
T	11	11	11	11	11	11	11	11	11
N	19159	19159	19159	19159	19159	19159	19159	19159	19159
Observations	186,711	186,711	186,711	186,711	186,711	186,711	186,711	186,711	186,711
R^2	0.859	0.646	0.490	0.628	0.440	0.668	0.477	0.431	0.552
Residual Std. Error (df = 167541)	95.475	132.308	139.451	97.422	111.258	69.734	44.592	77.097	43.119

Note: *p<0.1; **p<0.05; ***p<0.01

This table reports from a Within-OLS regression of adjudication on the share of a crop grown in each water right parcel with which that water right is associated. The regression estimated is $y_{it} = \beta \text{Post Adjudication}_{it} + \gamma_i + \gamma_t + \varepsilon_{it}$. Regression is weighted by the area of each parcel. Observations are at the individual water right parcel level. We observe 19159 water rights over 11 years of data. Panel is not perfectly square due to (a.) Water Right Transfers splitting up and moving water rights and (b.) Only partial satellite coverage for 2005 Crop Data. Standard Errors are robust clustered two ways at the Sub-Basin and Year Level. The Sub-Basin is the level in which most of the variation in the timing of adjudication operates. Certain crops have been aggregated from CDL observations (for example wheat includes summer and winter varietals). All non-agricultural land has been taken out of the regression, As such this regression only captures changes on the intensive rather than extensive margin.

Table 7: Impact of Adjudication on Types of Crops Planted

	Dependent variable:		
	Water Intensive	Drought Resistant	Fallow and Pasture
	(1)	(2)	(3)
After Adjudication	0.011	0.009	−0.019*
	(0.007)	(0.012)	(0.010)
Individual FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
T	11	11	11
N	19159	19159	19159
Observations	186,711	186,711	186,711
R^2	0.584	0.631	0.866
Residual Std. Error (df = 167541)	141.505	163.160	95.337

Note: *p<0.1; **p<0.05; ***p<0.01

This table is the same as the previous, except the crops are reported at a more aggregated level for easier interpretation: (a.) Drought Resistant Crops include Wheat, Barley and Alfalfa. (b.) Fallow and Pasture includes fallow land and pasture land and other hay crops. (c.) Water Intensive Crops include corn, sugar-beets, potatoes, and all other water intensive crops observed.

The table reports from a Within-OLS regression of adjudication on the share of a crop grown in each water right parcel with which that water right is associated. The regression estimated is $y_{it} = \beta \text{Post Adjudication}_{it} + \gamma_i + \gamma_t + \varepsilon_{it}$. Regression is weighted by the area of each parcel. Observations are at the individual water right parcel level. We observe 19159 water rights over 11 years of data. Panel is not perfectly square due to (a.) Water Right Transfers splitting up and moving water rights and (b.) Only partial satellite coverage for 2005 Crop Data. Standard Errors are robust clustered two ways at the Sub-Basin and Year Level. The Sub-Basin is the level in which most of the variation in the timing of adjudication operates. All non-agricultural land has been taken out of the regression, As such this regression only captures changes on the intensive rather than extensive margin.

Table 8: Impact of Buying / Selling Water on Crops Planted

	Dependent variable:					
	Water Intensive	Drought Resistant	Fallow and Pasture	Water Intensive	Drought Resistant	Fallow and Pasture
	(1)	(2)	(3)	(4)	(5)	(6)
After Buying Water Rights	0.003	0.052^{**}	-0.056^{***}			
	(0.010)	(0.023)	(0.020)			
After Selling Water Rights				0.006	-0.016^{*}	0.009
				(0.005)	(0.009)	(0.011)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
T	11	11	11	11	11	11
N	1845	1845	1845	1725	1725	1725
Observations	20295	20295	20295	18975	18975	18975
R^2	0.405	0.449	0.780	0.516	0.608	0.799

Note: *p<0.1; **p<0.05; ***p<0.01

This table presents the results of regressions which estimate how farmers change their crop choices after buying or selling Water Rights. The equation we estimate here is $y_{it} = \beta \text{After Buys/Sells Water Right}_{it} + \gamma_i + \gamma_t + \varepsilon_{i,t}$. Samples are restricted to individuals who either buy or sell Water Rights since these are the only individuals for whom there is identifying variation. Crops are grouped using the same scheme as previously described: (a.) Drought Resistant Crops include Wheat, Barley and Alfalfa. (b.) Fallow and Pasture includes fallow land and pasture land and other hay crops. (c.) Water Intensive Crops include corn, sugar-beets, potatoes, and all other water intensive crops observed.
Robust standard errors are clustered at two ways at the individual by Year level.

Table 9: Impact of Adjudication on Aggregate Acreage

	Dependent variable:					
	Log(Acres Irrigated)		Log(Total Acres)		Share of Acres Irrigated	
	(1)	(2)	(3)	(4)	(5)	(6)
Share of County Adjudicated	0.119	0.159*	−0.029	−0.027	0.034**	0.035**
	(0.087)	(0.090)	(0.048)	(0.049)	(0.016)	(0.015)
Parametric Time Trends	X		X		X	
Year FE		X		X		X
County FE	X	X	X	X	X	X
T	7	7	7	7	7	7
N	44	44	44	44	44	44
Observations	308	308	308	308	308	308
R^2	0.958	0.957	0.990	0.990	0.980	0.981

Note: *p<0.1; **p<0.05; ***p<0.01

The two panels on this table estimate the impact of adjudication on the share of irrigated acreage. Observations are at the county level and contain all 44 counties in Idaho, observations are included from the 7, 5-yearly Census of Agriculture between 1982-2012; specifications with county FE and year FE are as follows: $y_{it} = \beta \text{Share Adjudicated}_{it} + \gamma_i + \gamma_t + \varepsilon_{it}$. Specifications with parametric trends are: $y_{it} = \beta \text{Share Adjudicated}_{it} + \gamma_i + f(x) + \delta_{it} X_{it} + \varepsilon_{it}$, where $f(x)$ is a quadratic polynomial in calendar year, and X_{it} includes Idaho Produce Price Indices and Farm Cost Indices from FRED, and county-level annual growing degree days and precipitation from PRISM climate data. Standard Errors are robust clustered two ways at the County and Year Level.

Table 10: Impact of Water Right Adjudication on Aggregate Economic Variables

	Panel 1 - Dependent variable in Levels					
	Value of Land		Value of On-Farm Equipment and Machinery		Net Cash Income	
	(1)	(2)	(3)	(4)	(5)	(6)
Share of County Adjudicated	205,104.300*	210,031.700*	36,988.200**	35,428.010**	51,529.610	51,048.700*
	(107,518.000)	(116,755.700)	(14,751.620)	(15,545.620)	(33,376.720)	(26,442.960)
Parametric Time Trends	X		X		X	
Year FE		X		X		X
County FE	X	X	X	X	X	X
T	7	7	7	7	7	7
N	44	44	44	44	44	44
Observations	308	308	308	308	308	308
R^2	0.882	0.882	0.720	0.712	0.730	0.707
	Panel 2 - Dependent variable in Logs					
	Log(Value of Land)		Log(Value of On-Farm Equipment and Machinery)		Log(Net Cash Income)	
	(1)	(2)	(3)	(4)	(5)	(6)
Share of County Adjudicated	−0.210**	−0.189***	0.190	0.205	0.787**	0.811**
	(0.086)	(0.072)	(0.130)	(0.139)	(0.313)	(0.318)
Parametric Time Trends	X		X		X	
Year FE		X		X		X
County FE	X	X	X	X	X	X
T	7	7	7	7	7	7
N	44	44	44	44	44	44
Observations	308	308	308	308	308	308
R^2	0.963	0.962	0.774	0.769	0.863	0.859

Note: *p<0.1; **p<0.05; ***p<0.01

The two panels on this table estimate the impact of adjudication on economic outcomes from the Census of Agriculture. In the top panel outcome variables are measured in levels in the bottom panel variables are measured in logs. Observations are at the county level and contain all 44 counties in Idaho. Observations are included from seven 5-yearly Census of Agriculture between 1982-2012; Specifications with county FE and year FE are as follows: $y_{it} = \beta \text{Share Adjudicated}_{it} + \gamma_i + \gamma_t + \varepsilon_{it}$. Specifications with parametric trends are: $y_{it} = \beta \text{Share Adjudicated}_{it} + \gamma_i + f(x) + \delta_{it} X_{it} + \varepsilon_{it}$, where $f(x)$ is a quadratic polynomial in calendar year, and X_{it} includes Idaho Producer Price Indices and Farm Cost Indices from FRED, and county growing degree days and precipitation from the PRISM climate database. Standard Errors are robust clustered two ways at the County and Year Level.

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