The Value of Heterogeneous Property Rights and the Costs of Water Volatility

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May 2016

Abstract

The system of prior appropriation in the western Unites States prioritizes property rights for water based on the establishment of beneficial use, creating a hierarchy where rights initiated first are more secure. I estimate the demand for security in water rights through their capitalization in agricultural property markets in the Yakima River Basin, a major watershed in Washington State. All water rights are satisfied in an average year so the relative value of secure property rights is a function of water supply volatility, and the costs of droughts are predominantly born by those with weak rights. In aggregate, security in water rights does not capitalize into property values at the irrigation district level, however, there is heterogeneity in the premium for secure water rights. The lack of a premium for district level water security is robust to a variety of econometric methods to account for correlated district unobservables, and the null result produces an economically significant upper bound on the value to water security for the district. The ability for farmers to adapt to water supply volatility, as well as expectations about water markets and government infrastructure investment are leading explanations for the lack of an aggregate premium. These explanations are supported by the pattern of heterogeneity in the water security premium.

Keywords: water rights; hedonic valuation; water volatility; agricultural economics; Bayesian model averaging; boundary discontinuity

JEL Classification Numbers: Q15, Q21, Q24, Q25, Q54

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1 Introduction

Research on the efficiency and distributional effects of the institutions that govern water rights in the United States dates back to the inaugural issue of the American Economic Review (Coman, 1911), and, as noted in Libecap (2011), these issues are still relevant today. Water rights west of the 100th meridian in the United States are based on prior appropriation; a system where priority is defined by "first in time first in right". The first users to establish water rights in a watershed have priority over those that established rights at later dates. This contrasts to the riparian regime in most of the eastern (and wetter) U.S. where land ownership establishes rights to reasonable use of water. Ciriacy-Wantrup (1956) describes the the economic implications of differences between the two sets of institutions. The riparian regime includes legal uncertainty since new users of a water source may dilute the supply, while prior appropriation primarily suffers from physical uncertainty due to water supply volatility. The complexity in the prior appropriation doctrine leads to costly adjudication, present in almost all western states, to resolve conflicts regarding both the quantity and priority of water rights.[1] Burness and Quirk (1979) describe that in the absence of a competitive market for rights, the prior appropriation system creates inefficiency due to the unequal sharing of risk between property owners with junior and senior rights. The risk associated with water rights, particularly in areas governed by the appropriative regime, is proportional to the water volatility in a watershed. Thus, the institutional setting in the western U.S. directly links water supply volatility to welfare losses. This article models water volatility as the driver of a price premium for more secure (senior) water rights in agricultural property markets, and estimates the magnitude of the premium in a hedonic price model. In addition to estimating the value of senior water rights, the hedonic model informs policy-makers on the distributional effects of water scarcity, since the majority of costs associated with droughts fall on owners of junior water rights.

Climate models predict that regions around the world will face more variable water

[1] Data are available at http://www.judges.org/dividingthewaters/dtw-links.html.

supplies due to changes in precipitation patterns and higher temperatures that reduce water stored as snow pack. In particular, the western United States is expected to experience more frequent and severe droughts in the summer, which corresponds with peak water demand (Bates et al., 2008). A more volatile water supply will increase the value of secure water rights relative to insecure rights. The value of priority in water rights is difficult to directly quantify through water right transactions due the thinness of water markets. The goal of this article is to estimate the value of security in agricultural water rights through the hedonic method, and analyze heterogeneity in the underlying factors that drive the water security premium.

The idiosyncrasies of water institutions and the paucity of quality data on rights present challenges for a national or multi-state study on the economics of heterogeneous water rights. The Yakima River Basin in central Washington provides a suitable case study due to the dichotomous division of water rights in the basin and high quality data. High priority (also referred to as senior or non-proratable) rights were established before May 5th 1905, while all rights established after that date are designated as junior (or proratable) and are subject to curtailment when the water supply falls short of total entitlements.[2] Senior rights have never been curtailed; thus priority effectively insulates farmers from temporal water supply shocks. Downscaled climate models of the Pacific Northwest predict that the annual variance of the region's water supply will increase (Vano et al., 2010), resulting in more years when the region experiences water shortages. Water shortages that have historically occurred in 14% of years are predicted to increase to 77% of years during the 2080s for the IPCC's A1B scenario (Vano et al., 2010). Shortages do not stem from a decrease in total precipitation; rather climate change predominantly affects the water available during the irrigation season, from April to September. Intra-annual variation is predicted to be more extreme, with a higher percentage of rain falling during the winter. Lower volumes of snow

[2]There are actually three levels of water rights, with tribal water rights having the highest level of priority. However, in practice there has never been any conflict between senior water rights and tribal rights.

pack will further reduce water available for irrigation. If farmers expect that climate change impacts their water resources, or will do so in the future, the value of land with senior rights will rise relative to land with junior rights.

To evaluate the theory I employ the hedonic price model to estimate the premium associated with senior water rights. Using Bayesian model averaging (BMA) (Raftery et al., 1997) to address uncertainty in the true hedonic model, the empirical results indicate that, in aggregate, additional security associated with senior waters right is not capitalized into farm values. This result relies on variation in water rights across irrigation districts, which supply the majority of water used in the Yakima Basin. Therefore, it is difficult to assess the role of water rights in driving variation in prices relative to other unobserved factors specific to an irrigation district. For example, Buck et al. (2014) show that failing to control for spatial unobserved effects creates a downward bias in the estimates of the value of irrigation water.

I use two econometric approaches to address the issue of unobserved spatial heterogeneity a the district level. The first method is a cross sectional version of the Hausman-Taylor model (Hausman and Taylor, 1981) proposed by Abbott and Klaiber (2011), and the second is a boundary discontinuity analysis that compares parcels near the border separating junior and senior districts (Black, 1999). Both models, confirm that there is no statistically significant premium for senior rights at the district level. One explanation for the lack of a premium is that there are relatively low-cost mechanisms to cope with water supply volatility. There is evidence that groundwater mitigates the effects of water supply volatility since groundwater rights strongly capitalize into farm values in junior districts, but not in senior districts. After controlling for heterogeneity in the premium associated with groundwater rights and primary crop choice, there is a significant premium for senior water rights. This subpopulation with a significant premium likely has the highest costs of adapting to increased water supply volatility. The institutional setting of the Yakima Basin provides another explanation for the aggregate null result: expectations about future water volatility.

There are plans for the U.S. Bureau of Reclamation (USBR) to invest billions of dollars in increased storage capacity that will primarily benefit farmers in irrigation districts with insecure water rights. Therefore these farmers may perceive that realized water volatility will actually decrease in the future due to government intervention.

The null result in this setting is both economically significant and policy relevant. Using the posterior distributions to construct 95% confidence intervals for the value to irrigated agriculture from more secure water rights, I show that the upper bound of the hedonic estimates is still significantly less than estimates generated using a production function method. Therefore, the lack of statistical significance still yields an informative zero, and is not exclusively due to statistical noise. While this article focuses on the impacts in the Yakima River Basin of central Washington, the phenomenon of increasing water supply volatility applies to many regions facing a changing climate, particularly those that rely on snow pack as a source of water supply in the summer.

2 Background

2.1 Existing Literature

This article contributes to the literature by valuing heterogeneous water rights and connecting the relative value of secure rights to water supply volatility. Crouter (1987) first apply the hedonic price model to value water rights by testing functional forms of the hedonic price function to determine characteristics of the water market. Later studies estimate heterogeneity in the value of water due to differences in the productivity of the land (Faux and Perry, 1999) and the ecological value of in-stream flow (Netusil and Summers, 2009). In a recent study, Buck et al. (2014) utilize a panel dataset of sales to show that failing to control for parcel level unobservables creates a downward bias in the value of irrigation water. The existing research focuses on the total value of irrigation water, whereas research devoted to the impact of heterogeneity in water right security on land values is scarce. Other research analyzing property rights with varying degrees of security examines land rights in the developing world (Goldstein and Udry, 2008). Libecap (2011) presents qualitative analysis on the appropriative rights system and its effects on the efficient allocation of water between and within sectors.

The economic literature on estimating the costs of a variable water supply, developed by Tsur and Graham-Tomasi (1991), builds on the research of optimal groundwater extraction (Burt, 1964). Tsur and Graham-Tomasi (1991) coin the phrase "Stabilization Value" (SV) to explain the benefits from fixing a variable water supply at its mean. Research on the SV of water ranges from a static analysis outlining the benefits to buffering surface water with groundwater to a dynamic stochastic general equilibrium model (Tsur and Graham-Tomasi, 1991; Diao et al., 2008). Production function approaches are appropriate in a setting where the production function is static. However, these methods are biased if farmers change crops, irrigation and fertilization technologies, or land use (Mendelsohn et al., 1994). Alternatively, using property values to estimate the effect of water supply volatility incorporates the potential for landowners to adapt to changing economic and environmental conditions.

Mendelsohn et al. (1994) apply the Ricardian approach to estimate the impact of climate variables on the agricultural sector to avoid the bias in production function studies. The Ricardian approach utilizes the theory that land values should reflect the discounted value of expected profits, and therefore land rents are capitalized into farm values. National research on the economic value of water resources on agricultural land focuses on average precipitation (Schlenker et al., 2005; Deschenes and Greenstone, 2007). Mendelsohn and Dinar (2003) add surface water and a measure for water variance as independent variables in the Ricardian approach and find that surface water increases farm values while water variance depresses values. While these articles rely on county level data, Schlenker et al. (2007) use farm-level data in California to show that water availability strongly capitalizes into farm prices. Water supply volatility is also found to impact agricultural production and adaptation (Hansen et al., 2011; Connor et al., 2012).

The Ricardian studies use spatial variation to identity climate variables. Since the results are derived for a state or the entire country, they are more applicable in determining aggregate effects of climate change. Hedonic models, in contrast, often limit the sample to a small geographic area such as one particular county. This permits data with greater detail, and inherently controls for factors that vary spatially such as climate conditions and institutions. In fact Schlenker et al. (2007) intended to use water rights to describe water access, but the system of water rights in California proved too tortuous to obtain water rights data of sufficient quality. While national studies focus on climate variables that are outside of human control, the hedonic models explicitly value water resources that are actively managed, such as irrigation water and groundwater (Butsic and Netusil, 2007; Crouter, 1987; Faux and Perry, 1999; Netusil and Summers, 2009; Petrie and Taylor, 2007). In the national studies there is evidence that pooling irrigated and non-irrigated land is not appropriate since precipitation and temperature have very different impacts when land is augmented by irrigation (Schlenker et al., 2005; Fisher et al., 2012). An advantage of this research is that all land has access to irrigation, and thus circumvents the differential effects of climate on irrigated and dryland agriculture.

More recent research into the impact of water supply volatility in a hedonic framework finds that water volatility has a negative impact on farm values, controlling for average water supplies (Mukherjee and Schwabe, 2015). The article uses variation in water supplied to irrigation districts in California along with spatial estimates for groundwater quantity and quality. Access to a water supply portfolio, either through multiple irrigation districts or riparian surface water rights, increases farm values. While providing new estimates of a water supply for the costs of water supply volatility and the benefits to a portfolio, Mukherjee and Schwabe (2015) do not control for irrigation district unobservables nor do they have parcel level data on groundwater rights.

This article adds several contributions to the literature. First, I assess the costs of water volatility in a hedonic setting while both controlling for district level unobservables, and incorporating parcel level data on groundwater rights. Second, I focus on a region with a common set of institutions that connects the interpretation to the property right regime. In contrast, Mukherjee and Schwabe (2015) take a wider scope that spans multiple institutional settings; therefore the interpretation focuses on water resources as opposed to institutions. Lastly, I find substantially different results, since water security in the Yakima Basin does not capitalize into property values. Taken together, the results indicate that either water scarcity is a more severe problem in California, or Californian farmers have different expectations about future water supply volatility relative to farmers in Washington State. These findings highlight the need to directly incorporate expectations about water volatility and climate change into future research studying the impact of water supplies on irrigated agriculture.

2.2 Water Supply in the Yakima Basin

The Yakima River basin contains parts of Kittitas, Yakima, and Benton County, though Benton receives much of its water from the Columbia River (USBR, 2011b). Most of the precipitation in the region falls between October and March (USBR, 2002; Western Region Climate Center, 2010), and this trend will increase in the future based on climate models by Vano et al. (2010). The major water use in the region is irrigated agriculture, which is predominantly met by surface water. Five major reservoirs, operated by the USBR with a combined storage capacity of 1.07 million acre-feet (maf), serve six irrigation districts and a storage division that constitute the Yakima Project. Below Parker Gage, the major control point of the Yakima Project, the water supply is augmented by return flows from upstream use. The six irrigation districts served by the Yakima Project represent over 80% of the total water entitlements in the Yakima basin above Parker Gauge. The proportion of total rights increases when non-federally supplied irrigation districts are included, justifying the use of irrigation districts to value water right security in the Yakima Basin.

Actual deliveries exceed storage capacity because the reservoirs are filled throughout the year through precipitation and snow melt. In an average (non-drought) year the Yakima project delivers 1.7 million acres feet of water. Non-federal water use averages 590,000 acre-feet per year; surface water comprises two-thirds of this use, predominantly from private or local irrigation districts, with the remainder coming from groundwater (USBR, 2011b). In drought years surface water use declines and groundwater use increases. Therefore, even though groundwater only comprises 8.6% of total water use in an average year it plays a disproportionate role during droughts. This is consistent with groundwater having a buffer or stabilization value (Tsur and Graham-Tomasi, 1991; Diao et al., 2008).

The USBR operates reservoirs with the joint goals of flood control and the provision of irrigation water from April through September. Melting snow pack effectively acts as a sixth reservoir typically allowing the USBR to wait until June to begin drawing down the reservoirs for irrigation (USBR, 2002). Warmer temperatures cause earlier snow melt, preventing the use of snow melt during the irrigation season and reducing its substitutability with reservoir water. Therefore, the quantity and timing of snow pack is crucial to the water supply system in the Yakima Basin. Figure 1 illustrates historical deviations from mean withdrawals for each irrigation district in the Yakima project separated by the priority of water rights. There is a trend over time towards fewer withdrawals due to improvements in irrigation technology, conservation, and crop choice. Total annual diversions are relatively stable until the 1970s. However, since the 1990s the basin has experienced violent dips in water use due to severe droughts that were particularly acute for districts with a majority of junior rights. Kennewick Irrigation District (KID) only has junior rights but their position below Parker Gage allows some water to return in the form of recharge from upstream users as evidenced by smaller declines in withdrawals during droughts. The figure displays how senior water rights insulate landowners from water supply volatility, and motivates that the premium for this protection may be a function of climate change expectations.

2.3 Water Rights in the Yakima Basin

The institutions governing water rights in the Yakima River basin simplify the estimation of the costs of water volatility due to the dichotomous distinction of priority based on the date that beneficial use was established. All rights established prior to 1905 are classified as senior (non-proratable) rights, and all rights post-1905 are designated as junior (proratable). The law requires that senior right holders receive their full water allotment before honoring any junior right. Therefore, when supply is insufficient to fulfill the total apportionment of water rights in the basin, senior right holders receive their entire water commitment, and junior users divide the remaining water on a prorated basis.[3] The USBR determines the proration level at the beginning of the irrigation season based on forecasts of the Total Water Supply Available (TWSA), and adjusts the degree of prorating throughout the season in response to changing weather conditions. From 1970-2005 junior rights experienced prorating in 13 years whereas senior rights have never been prorated. Therefore, junior water rights holders are more susceptible to seasonal and annual variation, and will bear the majority of the costs as climate change affects water volatility in the basin.

Approximately 55% of the surface water rights in the basin are proratable, leaving a significant portion of farmers without water during a drought. Several irrigation districts have 100% senior rights and some districts have a mix of both non-proratable and proratable rights. I consider two ways to designate senior water rights. The first is simply the percentage of senior rights that a district holds, whereas the second establishes a discrete threshold for the percentage of rights that adequately insulates a district from the effects of a drought. I set the discrete threshold based on two reports from the USBR (USBR, 2011b,b) that indicate Roza, Kittitas, and Wapato all suffer severely from prorating during drought years. The highest proportion of senior rights in these districts is Wapato with 49% senior rights, so I set this as the cut-off for a district that is defined as senior. This cut-off conforms with the literature (Vano et al., 2010; USBR, 2011b) that prorating is particularly damaging below 70%, and the fact that junior districts experience withdrawal reductions

[3]For example, consider 50 landowners with junior rights and 50 with senior rights where each landowner has access to 1 ac-ft per year. If the water supply is 80 ac-ft in a specific year all the landowners with senior rights get their full share (1 ac-ft each) while those with junior rights are prorated at 60% since the 50 junior landowners must split the remaining 30 ac-ft.

more than 30% below their historical average in figure 1.

Table 1 shows the properties in the sample by irrigation district with the percentage of non-proratable rights, a junior or senior designation for the district, and average characteristics of the districts. The sample closely matches the population of water rights with 57.3% of properties having predominately junior rights. Water rights are not randomly assigned, and there may be differences beyond water supply security across irrigation districts. As seen in table 1, and in the discussion on agriculture in the Yakima Basin, there are differences in both the average price and the average size of the property. The empirical specifications attempt to control for unobserved heterogeneity at the district level while still capturing the capitalization of district-level water security. Figure 2 presents a map of the Yakima Basin and agricultural property sales within irrigation districts designated by seniority of water rights.

2.4 Agriculture in the Yakima River Basin

The Yakima River Basin in Central Washington State provides an excellent setting to examine the interaction of priority in water rights and water supply volatility because landowners with junior rights bear the preponderance of the costs of droughts. The Yakima River Basin is one of Washington's largest agricultural production regions, contributing close to 20% of the state's $9.2 billion worth of agricultural output in 2011.[4] Most of the land east of the Cascade mountain range in Washington State is very dry and relies on irrigation for agriculture. The Yakima basin is therefore susceptible to severe economic losses from drought. The Yakima Basin Storage Alliance (USBR, 2011a) estimates over $130 million in economic losses from decreased agricultural production from the 2001 drought alone.[5] The vast majority of these losses fell on farmers with junior water rights, while farmers with senior rights still received their full water allotment, allowing them to proceed with normal farming operations. More frequent severe drought years will diminish the relative value

[4]Data are available at http://agr.wa.gov/AgInWa/docs/126-CropProductionMap12-12.pdf - accessed 3/5/2013.

[5]Data are available at http://www.ybsa.org/agriculture.php - accessed 12/2/2012.

of farmland with junior water rights. Rational landowners will react to threats of water volatility, and this research tests whether they consider climate change as a real threat to their water supply.

The primary agricultural land uses in the Yakima Basin are pasture, hay, orchards, and vineyards, in addition to a variety of specialty crops such as hops and herbs. Table 2 displays the primary crops by irrigation district as a proportion of total parcels in the dataset, based on the USDA Cropscape data. As seen in table 2, there is substantial variation in agricultural land use across irrigation districts. There have also been changes in crop patterns and irrigation technology over time, perhaps in response to uncertainty in the water supply. Based on estimates from USBR (2011b), the consumptive use of irrigation from both crop switching and technology, has decreased by over 10,000 acre feet between the mid-1900s and 2011 for the three federal irrigation districts with the fewest proportion of senior water rights (Roza, Kittitas Reclamation, and Kennewick). Consumptive use for the remaining irrigation districts has increased slightly. Therefore, farms may switch crops as an adaptation strategy, but this will likely come at a cost relative to the unconstrained crop decision made in districts with more secure water rights. The next section describes the features of the Yakima basin, and motivates the use of water rights to test for expectations of water supply volatility.

2.5 Climate Change in the Yakima Basin

Water curtailments occur relatively frequently for junior water users, though when prorating is above 70% of normal entitlements farmers can generally cope by changing variable inputs and the timing of irrigation (Vano et al., 2010). Even though all prorating has costs, the most severe burden occurs in years where junior farmers receive less than 70% of their water rights. According to downscaled climate models by Vano et al. (2010) precipitation will increase in the cool months and decrease during the irrigation season. Rising temperatures will decrease the snow pack available, exacerbating water shortages for the agricultural sector. Historically, severe prorating occurred in 14% of years, but this is predicted to increase to 27-77% depending on the emissions scenario (Vano et al., 2010). On the demand side, rising temperatures will lead to higher evapotranspiration rates, increasing the water requirement of crops between 3% - 9.8%, depending on the area and study methodology (USBR, 2011b). In summary, climate changes will exert pressure on water supply and demand through reduced precipitation during the irrigation season, earlier snow pack, and higher temperatures. Furthermore, rising water supply volatility will increase the years where prorating is below 70%, predominantly impacting farmers with proratable water rights.

The Yakima River Basin Water Enhancement Program (YRBWEP) is evidence of the region's focus on addressing water scarcity. Beginning in 2009 the USBR and the Washington State Department of Ecology (ECY) began work on the YRBWEP with the goal of producing a Final Water Resources Integrated Management Plan (henceforth Integrated Plan). In addition to the two government agencies, members from the agricultural, environmental, legal, real estate, municipal and tribal communities participate as stakeholders in dealing with water scarcity in the region. If implemented, the Integrated Plan will cost between \$3.2-\$5.6 billion, with a base estimate of \$4 billion (USBR, 2011a). More than half of the expenditure will go towards enhancing the basin's storage capacity by constructing a new reservoir and upgrading existing storage facilities. A benefit cost study estimates that augmenting water resources through the Integrated Plan will increase irrigated agricultural production by \$400 million in net present value. This value comes solely from eliminating losses for farmers with junior water rights during droughts that cause less than 70% prorating under historical hydrologic conditions (USBR, 2011a). The cost estimates are biased downward because changes in water scarcity associated with climate change, and droughts resulting in prorating above 70% do not enter into the calculation. Conversely, the estimates do not account for adaptation such as crop switching or changes in irrigation technology, both of which ameliorate damages from droughts. Using property values to estimate the benefit of secure water availability will improve the methodology to quantify the benefits of the Integrated Plan.

3 Data

The primary data are sales of agricultural properties within an irrigation district located in the Yakima River Basin obtained from assessor offices for Kittitas, Yakima, and Benton Counties in Washington State. The assessors' office also provides data on zoning, land use, market improvements, and irrigation district boundaries. The sales data and the irrigation district boundaries are both geo-referenced allowing each parcel to be placed within an irrigation district using Geographical Information Systems (GIS) software; parcels outside of irrigation districts are dropped. Using sales within irrigation districts alleviates the problem of tracking distinct water rights for individual parcels. While most water rights remain with a physical parcel of land, it is possible for a landholder to sell all, or a fraction of, a water right, which obfuscates the link between a water right and parcel. Irrigation districts hold rights and distribute water to their members, ensuring that a farmer within a district receives the water benefits associated with the rights of the district. Complete water rights data, including the priority date, for major irrigation districts in the region are publicly available through the documentation of the Acquavella adjudication (Yakima County Superior Court, 2012).

I also incorporate data on supplemental water rights, which are predominantly groundwater rights, from the Washington State Department of Ecology. These additional water rights are spread evenly across irrigation districts, though there are a higher proportion of supplemental rights in irrigation districts with predominantly junior rights (8.7% compared to 6.8% in senior districts). Groundwater rights comprise 75% of the total supplemental rights owned by farms in the sample. As described above, even though supplemental rights are a small proportion of total water rights, and are generally not enough to fully sustain agriculture irrigation, they are used to supplement water from the irrigation district during drought years. Since the supplemental rights are predominantly groundwater I will interchange supplemental rights and groundwater rights throughout the article. To clarify, all parcels have water rights based on their irrigation district, and these rights comprise the majority of water use in the region. Within an irrigation district, rights are homogeneous and irrigation districts hold a fixed proportion of junior and senior rights. Therefore, the percentage of senior rights is a fixed characteristic of the irrigation district. The supplemental rights are established at the parcel level and vary within irrigation districts. Table 3 provides descriptions of variables used in the regression models, and table 4 displays the summary statistics.

In addition to water rights assigned at the irrigation district and parcel level, I add data on water supply variables at the basin level. The USBR produces estimates of the Total Water Supply Available (TWSA) for the Yakima Basin several times throughout the year, which determines the level of prorating of surface water supplies throughout the irrigation season. The April forecast is particularly important as it coincides with farmers planning their planting decisions for the irrigation season. These data are obtained through personal communication with Christopher Lynch of the USBR. I generate two variables based on the TWSA: a five-year rolling average of TWSA and negative deviations from the long-run average. The five year rolling average captures medium-run water availability for the region, whereas the deviations provide a proxy for the short-run downside volatility. This specification is a variation of downside volatility metrics used in finance such as the semi-variance, which is the squared deviations from the mean for observations that are less than the mean (Markowitz, 1968, 1991). Both TWSA and TWSA deviations are normalized by dividing by the standard deviation of TWSA.

I use sales from 1990-2011 to increase the likelihood of capturing changing expectations of water supply volatility. I spatially match soil characteristics from the Unites States Department of Agriculture (USDA) SOILMART (NRCS, 2009) database to individual parcels using GIS. The Consumer Price Index from the Bureau of Economic Analysis (BEA) normalizes all monetary values to 2008 dollars. Distance to cities, major streams, and the Yakima River are generated using GIS. Agricultural land use is measured through USDA's Cropscape spatial dataset (NASS, 2006-2010). The CropScape data overlap with the sales data for four years: 2006, 2007, 2009, and 2010. These yearly datasets are aggregated and dummy variables for the primary crop are created by determining the crop comprising the majority of land on the parcel over the four years where data are available. I also account for secondary crops by creating dummy variables for the most frequent minority crop on the parcel. Since there are many different crops, I aggregate crops into seven distinct categories as defined by the Washington State Department of Agriculture, and presented in table 2.

In order to address the spatial dependence I create variables comprised of characteristics of neighboring parcels. Lagged spatial values of the independent variables captures a significant amount of spatial dependence without imposing the considerable structure on the error term of a conventional spatial lag model (Kuminoff et al., 2010). I create spatial lags of slope, soil productivity, acres, value of improvements, and the residential indicator using six different spatial weight matrices, which are described in more detail below.

4 Economic and Econometric Model

4.1 Hedonic Model and the Cost of Water Volatility

I use the hedonic price model to estimate the implicit value of senior water rights in the Yakima basin. Rosen (1974) develops the hedonic price model in application to the residential housing market, and Palmquist and coauthors (Palmquist, 1989; Palmquist and Danielson, 1989) extend the model to land used for agricultural production. I derive the demand side of the market for agricultural land using per-acre variable profits gross of land payments, π_t^V

$$\pi_t^V = \mathbf{p_t} f_t(V_t, \mathbf{X}, W, \alpha) - c_t(V_t, \alpha) \tag{1}$$

where $\mathbf{p_t}$ is a vector of crop prices at time t, and f_t is the multiple output production function at time t that depends on a vector of fixed attributes of the land ($\mathbf{X}$), a farmer-specific unobserved skill parameter (α), the water availability on the land at time t (W_t), and a vector of variable inputs ($\mathbf{V_t}$). The cost function, c_t, depends on variable inputs and the idiosyncratic skill parameter. A farmer chooses $\mathbf{V_t}$ to maximize profits for any combination of $\mathbf{p_t}$, $f_{jt}()$, $\mathbf{X}$, W, and α, such that optimal profits can be expressed as,

$$\pi_t^{*V} = \pi_t^{*V}(\mathbf{p_t}, \mathbf{X}, W_t, \alpha) \tag{2}$$

The maximum bid that a farmer pays for a specific piece of land for use at time t is determined by the inputs of the profit function, as well as the desired net profits, π_t.

$$\theta_t(\mathbf{p_t}, \mathbf{X}, W_t, \alpha) = \pi_t^{*V}(\mathbf{p_t}, \mathbf{X}, W_t, \alpha) - \pi_t \tag{3}$$

By differentiating (3) it can be shown that $\frac{\partial \theta_t}{\partial X_i} = \frac{\partial \pi_t^{*V}}{\partial X_i}$ and $\frac{\partial \theta_t}{\partial W} = \frac{\partial \pi_t^{*V}}{\partial W}$. The derivative of the rental bid function is non-decreasing and concave in any desirable characteristic X_i and W_t, given typical assumptions of the variable profit function (Diewert, 1978). In equilibrium the marginal increase in variable profits must equal the marginal increase in the bid function, which in turn equals the rental price of land. The equilibrium rental schedule of land is an envelope of the bid functions. While equation (3) describes the decision for renting land for one-period, iterating the process into the future shows that the equilibrium sale price of land is equal to the expected discounted sum of future variable profits. In this context the increase in the market price, q_t, from a marginal increase in any attribute X, or W_t, will be the change in the discounted sum of expected current and future profits due to the extra amount of the attribute.

$$q_t(\mathbf{p_t}, \mathbf{X}, W_t, \alpha) = \sum_{h=t}^{\infty} E_h \left[\pi_h^{*V}(\mathbf{p_h}, \mathbf{X}, W_h, \alpha)\right] e^{-\beta h} \tag{4}$$

Analyzing the bid function for a permanent purchase of land as opposed to a one period rental iterates the process forward, where Θ_t is the bid for a permanent land purchase and $\bar{\pi}_t$ is the expectation of future net profits.

$$\Theta_t(\mathbf{p_t}, \mathbf{X}, \pi_t, W_t, \alpha) = \sum_{h=t}^{\infty} E_h \left[\pi_h^{*V}(\mathbf{p_h}, \mathbf{X}, W_h, \alpha)\right] e^{-\beta h} - \bar{\pi}_h \tag{5}$$

In this forward looking model $\frac{\partial \Theta_t}{\partial W_t} = \frac{\partial \sum_{h=t}^{\infty} E_h[\pi_h^{*V}] e^{-\beta h}}{\partial W_t}$; the marginal increase in the bid for land with better water resources equals the increase in the expected sum of discounted profits due to the water. This setup models the farmers' willingness to pay for secure water supply according to their expectations of the change in future profits. The literature on the stabilization value (Diao et al., 2008; Tsur and Graham-Tomasi, 1991) adds a theoretical background to the interpretation of a water right as an attribute of the hedonic price function. Let the premium on a senior water right, S, relative to a junior right, J, given all the characteristics of the property be defined as $E[P|X,S] - E[P|X,J] = \gamma$. Given that senior water rights are never prorated,[6] the premium is equal to the revenue from a fixed quantity of water less the expected revenue from a variable water supply, as seen in equation (6). The distribution of water $W \sim g(\mu, \sigma^2)$ can be described by its mean and variance, and $\tilde{\pi}()$ is the profit function optimized with respect to all other inputs conditional on W.[7]

$$\gamma = \sum_{h=t}^{\infty} \widetilde{\pi_h^{*V}}(\mu) e^{-\beta h} - E[\widetilde{\pi_h^{*V}}(W_h)] e^{-\beta h} \tag{6}$$

Note that the expectation operator is only applied to the profit for a junior landholder since their water input depends on the random variable W while senior landowners' profits depend on the constant μ. A Taylor series approximation of the junior landowners' expected profit, $E[\widetilde{\pi_t^{*V}}(W_t)]$, allows for the premium to be written as a function of the variance of the water supply.

$$\gamma = \gamma(\sigma^2) = -0.5 \widetilde{\pi_t^{*V}}''(\mu) \sigma^2 \tag{7}$$

This value is positive if the production function is concave in the water input, implying a diminishing marginal value of water.[8] Whether (7) holds in practice likely depends on the setting, particularly the domain of $\tilde{\pi}$. In this setting it appears feasible due the public

[6] This is likely a valid assumption considering senior rights have never been prorated.

[7] This assumption is relatively mild because the important aspect is landowners' perceptions of the distribution of the water supply which are unlikely to encompass anything beyond the first two moments.

[8] This assumption is difficult to assess because the profit function may not be continuous in water. There may be kinks where the water input causes the loss of a substantial portion of the crop or causes perennial crops, such as fruit trees, to die. Additionally, certain regions of the support may reflect changes in crop choice or land use.

discourse on the costs of water scarcity. The analysis does not rely on this assumption, but rather tests it directly by estimating γ as an attribute in the hedonic price with only the traditional assumptions in the hedonic model. The key point is that if $\gamma > 0$ then $\frac{\partial \gamma}{\partial \sigma^2} > 0$ is likely; and estimating a time-varying premium is an indication of changing expectations of water supply volatility.

4.2 Bayesian Regression Model

I employ a Bayesian linear regression model with normal independent Gamma priors as described by Koop (2003). The regression function is $y = X\beta + \varepsilon$, where y is the natural logarithm of the real sale price per acre, X is a matrix of covariates, β is a coefficient vector and ε is an idiosyncratic error term distributed $\varepsilon \sim N(0, \sigma^2\Omega)$. A Box Cox test (Box and Cox, 1964) estimates an optimal value of lambda as 0.06, very close to 0, which supports a log-linear model.[9] Though the confidence interval for lambda does not quite contain zero, I use the log-linear specification for its ease of interpretation. A graphical depiction of the test is available in the supplemental online appendix. The notation for any parameter θ follows Koop (2003) where $\underline{\theta}$ represents the prior value that is chosen by the analyst and $\bar{\theta}$ is the posterior value as a function of the data and the prior. I use diffuse priors with zero mean and a wide dispersion suggesting little prior information on the parameters.

This model produces a joint posterior distribution that is not of standard form. To estimate the model I draw directly from the conditional posterior distributions using the Gibbs sampler, a Markov Chain Monte Carlo (MCMC) method, to generate consistent estimates of the joint distribution. The Gibbs sampler sequentially draws from the full conditional posterior distributions of defined blocks, updating all the conditioning values in each run of the Gibbs sampler. The conditional posterior for β is the first block and is distributed multivariate normal, the second block is σ^2 with a gamma conditional posterior

[9] Xu et al. (1994) argue that the hedonic model may be mis-specified if there is potential for predicted values less than zero. The minimum predicted log per acre farm value is well above one, suggesting that there is not a cause for concern that the model will yield negative property values.

distribution.[10] The conditional posterior distributions for β and σ^2 are given by

$$p(\beta|y,\sigma^2,\Omega) \sim N(\bar{\beta},\bar{V}) \tag{8a}$$

$$p(\sigma^2|y,\beta,\Omega) \sim I\Gamma\left(\frac{\bar{\nu}}{2},\frac{\bar{\nu}\bar{s}^2}{2}\right) \tag{8b}$$

where $\bar{V} = (\underline{V}^{-1} + \sigma^{-2}X'\Omega^{-1}X)^{-1}, \bar{\beta} = \bar{V}(\underline{V}^{-1}\underline{\beta} + \sigma^{-2}X'\Omega^{-1}X\hat{\beta}(\Omega)),\ \bar{\nu} = n + \underline{\nu}$, and $\bar{s}^2 = \frac{(y-X\beta)'\Omega^{-1}(y-X\beta)+\underline{\nu}\underline{s}^2)}{\bar{\nu}}$.

I employ Bayesian estimation techniques for two reasons. The first is to alleviate omitted variable bias and model uncertainty from mis-specifying the empirical hedonic price function by using Bayesian Model Averaging (BMA). BMA accounts for the uncertainty inherent in model selection by weighting coefficients by the posterior model probabilities across all models. Additionally, the full distribution of the Bayesian posterior parameters in graphical format provides an intuitive way to present the results. A graphical approach focuses on the full parameter distribution as opposed to point estimates, while maintaining simple analogues to frequentist measures of inference. The posterior model probability for model i as shown in Koop (2003) is

$$p(M_i|y) = \frac{p(y|M_i)p(M_i)}{\sum_{m=1}^{M}[(y|M_m)p(M_m)]} \tag{9}$$

where y is the data, M is the total number of models, and $p(M_i)$ is the prior for model i that is set to $1/M$ for all models. There are 2^k potential linear models with k candidate regressors, making formal model selection computationally difficult as the number of candidate regressors increases. In this setting the 57 candidate regressors lead to over 1.4×10^{17} potential models, which makes estimating and evaluating each unique model intractable. Since there is likely multicollinearity between the candidate regressors I use a dilution prior that accomodates correlation between potential regressors based on George et al. (2010), and employed in the economic growth literature (Durlauf et al., 2012; Moser and Hofmarcher, 2014). One form of BMA developed by Raftery et al. (1997) takes advantage

[10]Ω is assumed to be a diagonal matrix, though this can assumption may be relaxed.

of Markov Chain Monte Carlo Model Composition (MC3) that precludes estimating each separate model and converges to the region with the highest model posterior probabilities. The MC3 method selects new models by either adding or removing a variable from the current model M_i and then assigning an acceptance probability as a function of posterior probabilities that dictates whether the new model M_j will replace the current model M_i given by $p(\text{accept new model}) = \min\left[1, \frac{p(M_j|y)}{p(M_i|y)}\right]$.

5 Results

5.1 Bayesian Model Averaging

Figure 3 presents the BMA results in a graphical format for regressions using either a senior dummy or the percentage of senior rights as fixed regressors.[11] The full set of parameters in figure 3 shows how often covariates are selected in the MC3 estimation for the top 50 models, and the color indicates the sign of the parameter. Table 5 highlights the results from the three separate BMA procedures. The first model does not include any fixed regressors and the second and third models include groundwater rights and either a senior dummy or percentage of senior rights as fixed regressors. These regressors are set as fixed since they are the variables of interest, and the goal of BMA is to sample from the models with different sets of control variables to account for model uncertainty. The coefficients are weighted by the posterior model probabilities, and assigned a value of zero for models in which they do not appear. The last column displays the posterior inclusion probability (PIP), which is the fraction of times the variable appears in all models.

While the results from the BMA can be interpreted directly it is also useful to select a baseline model to examine robustness and heterogeneity. To be conservative when selecting a base model I include all variables that show up at least once in any of the top 50 models from the specifications with fixed regressors. New models are thus compared to both the base model and the BMA results.

[11]The BMA was undertaken using the BMS package in R developed on the methodology in Feldkircher and Zeugner (2009).

As seen in the first section of table 5 neither senior rights nor supplemental rights are probable predictors in the BMA without fixed regressors. The PIPs for the senior dummy, senior percentage, and groundwater rights are 0.02, 0.01, and 0.09 respectively. The low PIPs are evidence that even if water rights do capitalize into farm values, they do not explain as much variation in property values compared to variables such as the size of the farm and the value of improvements. The low inclusion probabilities weight the coefficients towards zero, but even when the senior dummy and percentage senior variables are included as fixed regressors the posterior means are small and statistically insignificant. Although water security at the district level does not appear to capitalize into farm values, groundwater at the parcel level does increase property values. The inclusion probability is higher, and when groundwater is included as a fixed regressor the mean of the posterior is positive and statistically significant at 12.4%. Further analysis of the interaction between groundwater rights and district level rights is discussed below.

The BMA results indicate that senior rights do not capitalize into farm values, but it is important to understand what is driving the results. Therefore, I use the BMA as a variable selection tool and develop a base model to test specific questions dictated by economic theory. The rest of the article focuses on the parameters related to water rights. However, several elements of the identification strategy should be noted. In addition to model averaging to cover model uncertainty I flexibly control for spatial effects by including spatial lags of independent variables as well as third order polynomials of all continuous spatial covariates in the set of candidate regressors. I test for six different specifications of the spatial weight matrix used to generate the spatial lags of the independent variables: 10 nearest neighbors (NN), 20 NN, inverse distance for 10 NN, inverse distance for 10 NN, inverse distance for all neighbors within 10 kilometers, and inverse distance for all neighbors within 20 kilometers. In model specification tests from the BMA regression the 20 nearest neighbors weighted by inverse distance produces the best model fit based on the mean squared error. To control for temporal effects I include third order polynomials of a monthly time trends and a one year rolling average of agricultural sales in the basin. The full set of posterior parameters for the BMA regression with no fixed regressors are available in table A.1 of the supplemental online appendix.

5.2 Base Model

The posterior distributions of the senior right variables demonstrates whether land with senior water rights sells at a premium. A dummy variable identifies parcels in a district with access to sufficient senior water rights to insulate them from water supply shocks, and the percentage of senior rights provides a continuous measure of water security within irrigation districts. Figure 4 shows the densities of the posterior distribution for both the senior dummy and the percentage senior variables from the base model. The shaded region is the 95% highest posterior density (HPD) - the Bayesian analogue to a 95% confidence interval. The mean of the posteriors for the senior dummy is 4.9% and 8.3% for the percentage of senior rights.[12] Both parameters have a significant portion of the HPD below zero indicating that the central tendency of the distribution is not statistically significant from zero. The base model corroborates the BMA results with respect to groundwater rights; the posterior mean of the distribution for supplemental water rights in the base model is 13.5% and statistically significant (see table A.2). The full set of posterior estimates for regressions with both specifications of senior rights (dummy and percent) are available in tables A.2 and A.3 in the supplemental online appendix.

One of the challenges in estimating the demand for senior water rights in the Yakima Basin is that most of the rights are held by irrigation districts. While irrigation districts have reliable water rights data, the identification of the main parameter is based on variation across irrigation districts. Standard regression models cannot separately identify the water rights premium and the idiosyncratic irrigation district effects. Most of the irrigation district effects can be flexibly controlled for by observable parcel characteristics, however,

[12]Since most districts have some senior rights, when interpreting the percentage senior rights parameter the coefficient should be multiplied by the percentage points necessary to achieve water security; this ranges from 20-70% depending on the district.

I cannot control for irrigation district fixed effects in this framework without losing the primary variation in water rights. One area where this poses a problem is with the Wapato Irrigation Project (WIP). This district is contained within the Yakima Nation Reservation and thus may have important district level unobservables that are not captured by the percentage of water rights. In the BMA estimation a dummy for the reservation is negative and strongly significant. This essentially removes 19% of the junior sales from identifying the effect of senior water rights. As seen in table 1, WIP has the lowest average farm values of any irrigation district, and it is uncertain whether the lower farm values in WIP are due to lack of water security or unobservable features of the reservation.[13] To investigate the role of the reservation, I estimate the base model excluding the reservation dummy. The posterior estimates for models with and without the reservation dummy, for both the senior dummy and percentage specifications, are displayed in figure 5. It is clear that excluding the reservation dummy causes the premium to increase for both specifications, and the HPD does not include zero for either the senior dummy or the senior percentage specification without the reservation indicator. The senior rights premium is 8.5% based on the posterior mean in the dummy specification without controlling for the Yakima reservation. The differences in the results demonstrate the importance of district level unobservables in estimating the value of water rights, and require a more detailed investigation into potential endogeneity.

5.3 District-level Unobservables

The justification to exclude the reservation dummy relies on the assumption that there are no idiosyncratic effects at the irrigation district level that are correlated with senior water rights. Since senior rights vary at the irrigation district level, it is not possible to estimate the district-level value of water security while controlling for district-level unobservables with fixed effects. I employ two empirical approaches to identify the value of water security

[13]Land in WIP does not need to be owned by members of the Yakima Nation and property is freely traded and developed by non-tribe members.

at the irrigation district level in the presence of district-level unobserved heterogeneity: a cross-sectional Hausman-Taylor (HT) model and a boundary discontinuity analysis.

Abbott and Klaiber (2011) describe the challenge of identifying capitalization effects of spatially delimited amenities in hedonic models at different spatial scales in the presence of correlated spatial unobservables. Models that include spatial fixed effects consistently estimate the capitalization effect at spatial scales lower than the fixed effects, but ignore capitalization effects at spatial scales at, or above, the spatial fixed effect. For water security in the Yakima Basin, including district level fixed effects generates consistent estimates of the value of supplemental water rights, which vary within irrigation district, but ignores the capitalization of water security at the district level. This is problematic since water provided through irrigation districts comprises the vast majority of the irrigation supply in the basin. Abbott and Klaiber (2011) present a solution to this problem by implementing a cross sectional adaptation of the HT model (Hausman and Taylor, 1981). The main intuition for this model in the current setting is that within-district exogenous variables that are correlated with senior status, but not with the unobserved district effect, can be used as instruments.

The estimation occurs in three steps. First, a regression with irrigation district fixed effects generates consistent estimates of covariates of interest that vary within irrigation districts, in our case supplemental water rights. Next, the the residuals from the first step are regressed on district-varying covariates, which allows a GLS transformation of all variables. Finally, the GLS-transformed variables are used in an instrumental variable model with the instruments created by the following transformations of the variables. All covariates varying within irrigation districts undergo the within-transformation, and district level averages are calculated for all exogenous variables. The estimation relies on exogenous regressors that vary within districts and are correlated with senior rights. I use a third order polynomial for distance to a stream and the distance to the nearest city.[14] The

[14]Higher order terms of distance to a city are not included since they do not enter the base regression

correlation between the senior dummy and distance to a stream is -0.27, and the correlation between senior dummy and distance to a city is 0.33. Abbott and Klaiber (2011) suggest a pseudo-Hausman test for exogeneity of the instruments by running an OLS regression augmented by the within-transformation of all the variables. The coefficients on the within-transformed exogenous variables should not be significantly different from zero to validate their use as instruments.

The results of the HT model are presented in table 6.[15] The first panel displays the coefficient estimates for the senior dummy and groundwater rights based on the HT model. Senior water right do not capitalize into farm values even after controlling for district-level unobservables. The groundwater parameter decreases slightly in magnitude and significance; the p-value is 0.086. The HT results therefore support the primary results from both the BMA and the base model with the reservation dummy. The second panel of table 6 shows the result for validity tests of the instruments based on the auxiliary OLS regression suggested by Abbott and Klaiber (2011). The within-transformed coefficients (designated by a hat symbol) for a third order polynomial of distance to a stream and distance to the city are all insignificant, indicating they are valid instruments. Additionally, the within-transformed coefficient on groundwater rights serves as a test of endogeneity of groundwater rights with respect to district level unobservables. The within-transformed groundwater coefficient is also insignificant, indicating no significant correlation between groundwater rights and district level unobservables. Therefore, in the subsequent analysis I investigate the heterogeneity in the groundwater rights without district fixed effects. The HT estimates broadly support the base results that water supply security capitalizes into farm values through groundwater access, but not at the irrigation district level through more secure surface water rights. The posterior mean on the senior dummy from the base regression is 0.049, which is very similar to the point estimate from the HT regression

model, and the HT estimation relies on transformations of variables in the standard model.

[15]Note that the Hausman-Taylor estimates are not conducted in the Bayesian framework.

of 0.041, and both parameter estimates are not statistically different from zero. This, in addition to the lack of endogeneity of groundwater rights, provides evidence that controlling for the Yakima Nation reservation is sufficient to avoid the problem of district-level endogeneity. I further assesses district-level unobservables with a boundary discontinuity design.

An early method to address spatially correlated unobservables is the boundary discontinuity analysis based on Black (1999). Boundary discontinuity analysis relaxes the orthogonality assumption by assuming that any unobserved spatial effects specific to an irrigation district diminish along with the distance between two irrigation districts. In this context parcels on either side of the border of an irrigation district are more comparable than distant parcels. I establish the samples for the boundary discontinuity analysis by creating overlapping buffers of 1, 2, 3, 4, and 5 miles from the border of both junior and senior districts. Parcels that lie in the overlapping junior and senior district buffers for each of the five distances comprise the five new samples. In this setup the 1 mile buffer has the least stringent assumptions on uncorrelated district-level unobservables, and the 5 mile buffer requires the strongest assumptions of all boundary discontinuity models. The resulting sample sizes are shown in table 8. Figure 6 shows how the boundary discontinuity design works in a subset of the sample area.

In a hedonic setting it is important to consider the market extent when estimating the implicit prices for amenities. To assess differences across the buffer subsamples I compare the averages within the subsamples (panel (a) of table 7). I also perform two specification tests. To test for the statistical significance in the differences in the variables across the subsamples I regress each variable on a set of dummy variables for each subsample.[16] Panel (b) of table 7 displays the F-statistic for the test of joint significance as well as the accompanying p-value. Price and the value of improvement are jointly significantly differ-

[16]Since primary crop is a categorical variable, I instead regress the dummy variable for having orchard as the primary crop on the five subsample dummies, as seen in panel (b) of table 7.

ent across the five subsamples at the 5% level, and the year of sale and the proportion of orchards are significant at the 10% level. Groundwater rights and the percentage of senior rights at the irrigation district do not vary significantly across the boundary discontinuity samples. While this test describes that there are differences in average levels of the variables in the different samples, the more important test is whether the implicit prices vary significantly across the subsamples. If the market extent is not consistent within the subsamples the results from the boundary discontinuity samples may not be extrapolated to the broader region. To test for changes in implicit prices, I run separate regressions for each buffer using the whole sample that interact all variables in the base model with a dummy for the buffer sample. Joint significance of the interaction terms is evidence that implicit prices are not consistent within the subsamples. Panel (c) of table 7 presents the F-statistic for joint significant of all the interaction terms along with the p-values. None of the buffers produce jointly significant interactions, which motivates the consistency of the boundary discontinuity method.

The boundary discontinuity analysis relaxes the need for irrigation level fixed effects by restricting the sample to parcels that are comparable. Therefore the regression models include all covariates of the base model *except* the reservation fixed effect. The posterior distributions for the senior dummy for each of the buffer zones are shown in figure 7; the mean, standard deviation and sample sizes are presented in table 8. The posterior mean for senior water rights in the full sample is positive and statistically significant when excluding the reservation dummy, but none of the estimates in the boundary discontinuity samples have statistically significant posterior means. This is consistent with the HT estimates. One explanation for the insignificant results is that restricting the sample to observations close to the border of an irrigation district reduces the sample size, and therefore increases the standard deviation of the posterior. However, even though the standard deviation does increase as the sample size decreases, the largest mean of the posterior distribution for any the buffers is approximately half the size of the estimate in the full sample. The boundary discontinuity results, combined with the HT estimates, indicate that idiosyncratic district-level effects are important and the reservation dummy belongs in the model. Based on all appropriate specifications, water security at the district level does not capitalize into agricultural property values.

6 Robustness

I perform three robustness checks to confirm the accuracy of the BMA and base results. First, I limit the sample size and add additional control variables. Second, I incorporate estimated water deliveries to the districts as an alternative specifications of water security, and generate interactions between the senior dummy and a variety of water supply variables. Lastly, I examine if the senior premium is non-stationary, and may evolve along with expectations of future water supply volatility.

The results of the first robustness test are presented in table 9, where the posterior means for senior and groundwater rights are displayed for a variety of specifications with the corresponding 95% HPD below in brackets. Column (1) presents the base specification as a means of comparison. The model presented in column (2) removes properties that have a primary land use as developed, and column (3) drops additional properties that have residential structures. While all properties are zoned as agricultural land, these observations may be less reliant on farming as their primary income source, and thus are less susceptible to water supply volatility. Column (4) removes the top 10% and bottom 10% of observations based on the sale price and column (5) removes the top and bottom 10% of observations based on the total acreage. In columns (6)-(8) I add more flexible time and market level controls. Column (6) adds year fixed effects, column (7) interacts the third order time trend with county dummies, and column (8) interacts the third order rolling average with county dummies. In every specification the 95% HPD for the senior premium contains zero, and point estimates do not change dramatically across specifications. In fact, the 90% HPD interval also contains zero in every specification as presented in table A.7

in the supplemental online appendix. The 95% HPD for groundwater rights excludes zero in all but one of the specifications. Overall, both the lack of a senior premium, and the positive capitalization of groundwater rights, are robust to a variety of sample and control specifications.

6.1 Water Supply and Senior Water Rights

The base model values water security as the institutional right to water security. Senior water rights have never been curtailed, but the actual water supplied to districts with junior rights depends on both the priority of the right and hydrological conditions. I test whether realized water deliveries to districts capitalizes into farm values by estimating the annual water delivered to a district on a per acre basis. Each district is entitled to a fixed quantity of water annually, but junior entitlements are prorated in years where the water supply cannot cover all entitlements in the Basin. The deliveries variable multiplies each districts' per acre entitlement (total entitlement divided by irrigable acres) by the proportion of water rights delivered each year. The proportion of rights is the percentage of senior rights plus the annual prorating rate multiplied by the percentage of junior water rights. This proportion equals one for all districts in a year without prorating, and decreases as the prorating level decreases and the proportion of junior rights increases. The proportion always equals one for districts with 100% senior rights. Since water deliveries vary over time, I can identify the impact of annual deviations from average deliveries by adding district fixed effects into the model.

Table 10 shows the results from three specifications (columns (1)-(3)) of regressions that explicitly incorporate water deliveries into the model. The first row for each variable in table 10 displays the posterior mean, with the 95% HPD underneath. Column (1) simply replaces the senior dummy with the water delivery variable, which is negative and insignificant. The sign of the posterior mean is counter-intuitive since property values should increase when more water is available to a district, but it is not significant. The regression does account for the aggregate water supply with variables for the rolling average of TWSA and deviations from long-run TWSA, so the delivery variable primarily accounts for cross sectional variation in water deliveries. The model in column (2) includes both deliveries and the senior dummy; the water deliveries parameter does not change substantially, nor is the mean of the senior posterior significant. Column (3) includes district fixed effects, and deliveries produce a larger negative effect on property values in this specification. When interpreting the estimates of deliveries in the fixed effects model, it is important to recognize that the fixed effects soak up substantial cross sectional variation, and the water supply variables capture much of the time series variation. Lastly, column (4) displays the results from a model that interacts the senior dummy with deviations from TWSA, excluding any delivery variables. The interaction term in column (4) is negative and insignificant, indicating that senior water rights are perhaps less valuable during periods of low water supply. Recall that TWSA deviations only includes negative deviations and is normalized by the long-run standard deviation. Therefore, the interpretation of the posterior mean is that land with senior water rights decreases by 6.4% for one standard deviation decrease in the water supply relative to land with junior rights. The results are not statistically significant, but they corroborate the results of water deliveries that water security is not capitalized through short-run variation in the water supply.

6.2 Non-Stationary Costs of Water Volatility

Lastly, I assess the possibility that the senior premium is time-varying, with the expectation that recent droughts and growing attention to climate change will increase the premium over time. This is a different exercise than incorporating water deliveries and interacting the senior dummy with TWSA deviations. Those regressions test whether short-run annual variation in water availability is connected to district-level water security. It is possible that perceptions about climate change caused a permanent shift in expectations about water volatility in the region, and consequently, the premium for land in senior districts. I do not have data on attitudes or perceptions about climate change so it is necessary to propose plausible climate change scenarios in order to test for changing expectations about water volatility.

The first approach assumes that severe droughts serve as an information shock that, coupled with news and research about climate change, changes landowners' expectations. There have been two severe droughts that reduced prorating to below 70% since the year 2000: in 2001 and 2005.[17] I run a difference-in-difference model that includes a dummy for all observations after the drought as well as an interaction term of the senior water rights dummy with the post-drought dummy. Two separate regressions are run for the 2001 and 2005 droughts. I also adapt this specification by changing the dummy to include only two years after the respective drought, which has the interpretation of a short-run impact of the drought on the senior premium. Comparing the short-run specification to the long-run specification tests whether the response of property markets to the drought dissipates after two years.

Figure 8 shows the posterior distributions for the senior water right coefficient and each post-drought interaction as a grid; the columns designate each drought and the rows represent the time horizon. The results from the long-run specification for either drought do not provide evidence that the premium for senior rights increases after a drought. In fact, the interaction term is negative for both droughts, indicating that the senior premium actually decreases after a severe drought. The 95% HPD for all coefficients includes zero, indicating that the effects are not statistically significant. The short-run effects show that there may have been a small temporary increase in the senior premium after the 2001 drought, but the posterior mean of the interaction term is not statistically significant. Additionally, the temporary increase in the premium after the 2001 drought was counterbalanced by a short-run decrease in the premium after the 2005 drought, which is statistically significant.

An additional test for a time-varying parameter assumes expectations about the severity of climate change increase smoothly over time. For this specification I interact both a linear

[17] There was one other prorating period below 70% in the sample - the 1992-1994 drought. However, less than 10% of the observations occurred prior to the drought.

and quadratic time trend with the senior dummy, and in both cases the interaction terms are not significant. In fact, in the linear trend specification the mean of the posterior for the interaction term is negative. The results for both regressions are in tables A.4 and A.5 in the supplemental online appendix.

7 Interpretation & Heterogeneity

The lack of a senior premium is not intuitive given the Yakima Basin's recent experience with drought and the significant effort put into the Integrated Plan. In the economic model the water security premium is defined as $\gamma(\sigma^2)$, and thus is a function of water volatility. Since land sales are forward looking, the premium depends on expectations of water volatility. The premium can therefore be decomposed into exceptions of future water volatility and the cost that water volatility imposes on farm income. The lack of a senior premium means that either farmers' do not expect that water volatility will be a concern in the future, or that there are relatively low cost mechanisms to adapt to water volatility.

7.1 Institutional Explanations

While I do not have direct empirical evidence of farmers expectations, there are two institutional developments that may explain why farmers expect the future water supply to be relatively stable. The first is the expectation that the Integrated Plan, which will build a new reservoir, will substantially reduce water volatility in the region. This plan involves massive federal government investment that primarily benefits farmers with junior rights, and it is reasonable for the expectation of this investment to depress the senior premium.[18] Furthermore, the development of active water markets in the region has the potential to change farmers expectations of water availability during droughts. Yoder et al. (2014), who find minimal benefits to agriculture from increasing storage capacity, show water markets decrease the agricultural costs of droughts in the region to approximately one-third

[18] While the Integrated Plan is not yet approved, the logic is similar to an increase in property values near the California high speed rail prior to approval and completion.

of the no-markets scenario. While there are not fully active water markets in the Yakima Basin, there have been early developments of trading between senior and junior districts in Yakima County. Additionally, one of the policy responses discussed in the event that the Integrated Plan does not create additional water storage is the development of a more active water market. Both increased storage capacity and water markets will decrease the relevant water volatility faced by farmers with junior rights. The institutional context surrounding the Integrated Plan supports the notion that farmers may expect a relatively stable water supply in the future, and thus helps explain the lack of a water security premium. However, this claim cannot be directly tested empirically.

7.2 Heterogeneity in Senior Rights

I investigate the costs of coping with water volatility (conditional on expectations) empirically by analyzing the heterogeneity of the senior premium related to adaptation. I analyze two sources of heterogeneity that may provide mechanisms for farmers to adapt to water supply volatility: groundwater rights and crop choice. The interaction between senior water rights and groundwater rights is important because access to groundwater rights serves as a buffer to water supply volatility (Tsur and Graham-Tomasi, 1991). Additionally, an incongruence exists between the lack of capitalization of irrigation district water rights, and the strong positive capitalization of groundwater rights. These results suggest that there may be an interaction between irrigation district and groundwater rights. Secondly, I analyze the relationship between senior rights and orchards since orchards are a valuable land use that requires water to maintain the capital investment (fruit trees). Olen et al. (2016) establish a connection between crop choice and irrigation decisions in the context of climate induced water scarcity.

As explained earlier, supplemental rights (predominantly groundwater) are unlikely to be the primary source of irrigation, but offer extra water to stabilize irrigation needs during a drought. According to the theory, the value of a senior right stems from insulating the landowner from water supply shocks; the benefits of supplemental rights should be greater for farmers whose primary surface water rights are junior. Table 11 shows the mean and 95% HPD of posterior distributions from regressions that interact the senior dummy with dummies for groundwater rights and orchards. Moving from the base model (column (1)) to a model that includes the interaction of senior with groundwater rights (column (2)) shows that the posterior distributions for the senior premium and the groundwater rights both shift to the right. The interaction of senior and groundwater is negative and is marginally significant; the 90% HPD just barely includes zero (see table A.8 in the supplemental appendix). The mean of the posteriors indicate that supplemental rights add 2% (the joint effect of groundwater and senior×groundwater interaction) to the value of a farm in a senior district compared to 20% for a farm in a junior district. The fact that supplemental rights predominantly benefits those with junior district rights supports the initial claim that water rights are heterogeneous and priority insulates landowners from the effects of drought. This is consistent with Mukherjee and Schwabe (2015) who find that access to a diversified portfolio of water resources increases land values, and including alternative sources in the econometric model decreases the value of primary rights.

The results in column (3), where the senior dummy is interacted with a dummy for orchards, show a similar effect. The senior premium posterior shifts to the right, and the interaction term of senior and orchard dummies is negative, with zero barely outside the 95% HPD. Land with either junior or senior rights is more valuable employed as orchards, but the premium for orchards is roughly two times higher for land with junior rights. Orchards generally require a stable water supply to protect the capital asset; 17% of land in junior districts is primarily orchard compared to 25% in senior districts.[19] Furthermore, orchards in junior districts are more than twice as likely to have supplemental rights compared to orchards in senior districts (33.3% compared to 15.5%), a difference that is statistically significant. These results indicate that some farms in junior districts may convert to orchards if they have more secure water rights. Those junior farms that are able to maintain

[19]The means are statistically different from each other at the 1% level see table A.6.

orchards augment their water supply with groundwater rights, or perhaps take unobserved actions such as investing in efficient irrigation equipment. After controlling for heterogeneity in both groundwater and orchards (column (4) of table 11), the mean senior premium increases to 9.6% and the 95% HPD excludes zero. Although the aggregate senior premium is not statistically significant, there is a significant senior premium for the population without groundwater and fruit trees, a population seemingly least able to adapt to water volatility.

7.3 Policy Scenario

The Integrated Plan is a strategy to address water scarcity in the region as farmers face droughts and the dearth of new water rights constrains developments. For agricultural producers, enhancing storage capacity will decrease the volatility of water deliveries to junior districts, making them more similar to senior districts. Using the estimates of the relative premium for farmland with senior rights to calculate the benefits to the agricultural sector from storage enhancement in the Integrated Plan provides an alternative to the production function approach used by the USBR. None of the posterior means or point estimates for surface water security are statistically significant, so I calculate confidence intervals for the dollar value of irrigation benefits to compare with benefits estimated by the Integrated Plan. The exercise generates an upper bound of the benefits and reveals whether the insignificant results are merely the product of statistical noise, or if there are important insights based on the upper bound of irrigation benefits.[20] The gains to agricultural production are calculated by multiplying the 95% HPD for the per-acre premium for land with senior water rights by the irrigable acres of land with junior rights. I only use land served by the Yakima Project since data are readily available, making the results an effective lower bound on the benefits for the whole basin. This approach is justified since these districts represent a significant proportion of total agricultural land and the estimates can be directly compared

[20]The approach is similar to Hanna et al. (2016) who find a null result for the effect of improved cook stoves on pneumonia in India, and use a 95% confidence interval to compare the results to prior studies.

to the results in the Integrated Plan. Using the hedonic approach the upper bound of the 95% confidence interval for benefits from more secure water rights ranges between \$161 million and \$282 million depending on the model specification. All of the 95% confidence intervals for the benefits include zero, and the upper bound for the Hausman-Taylor results primarily reflects a larger standard error as opposed to a higher point estimate. The largest upper bound is still more than \$100 million lower than the \$400 million estimate in the Integrated Plan, suggesting an upward bias in the production approach that does not account for landowner adaptation.

8 Conclusion

Increasingly frequent demand and supply shocks, potentially due to climate change, are raising awareness of water scarcity for agricultural producers in the western United States. The aggregate and distributional effects of water scarcity are intimately related to the institutions that govern water rights. This article quantifies the value of priority for water rights as a mechanism that protects landowners from the effects of droughts. In aggregate, the central tendency of the posterior distribution for senior water rights is insignificant under all reliable specifications.

The results are robust to two empirical techniques that address potential district-level endogeneity: a Hausman-Taylor type estimator (Abbott and Klaiber, 2011) and a boundary discontinuity design (Black, 1999). The null result is economically significant as opposed to simply arising from statistical noise. Using the estimates from the posterior distribution to build confidence intervals for the value of irrigation benefits from more secure water shows that the methodology employed by the Integrated Plan overestimates the agricultural benefits associated with enhanced storage capacity in the basin. Though the discourse from the Integrated Plan suggests that the problem of water security in the Yakima Basin is becoming more severe over time, tests for a time-varying premium for water security do not support this claim. Rather, the premium may have decreased over time, and after severe droughts.

There are two explanations for the lack of a senior premium. First, there may be relatively cheap solutions for addressing water supply volatility, such as supplementing water from irrigation districts with privately held groundwater rights. Supplemental rights, predominantly groundwater, strongly capitalize into farm values in irrigation districts with junior rights, whereas they do not increase farm values in senior districts. Controlling for heterogeneity in the senior premium due to groundwater rights and crop choice indicates that water security does capitalize into farm values for the section of the population leas able to adapt to the costs of water volatility. The second explanation is that expectations of government investment in new storage capacity, and the proposed development of water markets, reduce the perceived future water supply volatility. Future research can explicitly model perceptions of future water supply volatility to better understand how climate change affects the value of water security.

References

Abbott, Joshua K and H Allen Klaiber, "An Embarrassment of Riches: Confronting Omitted Variable Bias and Multi-Scale Capitalization in Hedonic Price Models," *Review of Economics and Statistics*, 2011, *93* (4), 1331–1342.

Bates, Bryson, Zbigniew W. Kundzewicz, Shaohong Wu, and Jean Palutikof, "Climate Change and Water," Technical Report, Technical Paper of the Intergovernmantal Panel on Climate Change, IPCC Secretariat, Geneva 2008.

Black, Sandra E, "Do better schools matter? Parental valuation of elementary education," *Quarterly Journal of Economics*, 1999, pp. 577–599.

Box, George EP and David R Cox, "An analysis of transformations," *Journal of the Royal Statistical Society. Series B (Methodological)*, 1964, pp. 211–252.

Buck, Steven, Maximilian Auffhammer, and David Sunding, "Land markets and the value of water: Hedonic analysis using repeat sales of farmland," *American Journal of Agricultural Economics*, 2014, *96* (4), 953–969.

Burness, Stuart H. and James P. Quirk, "Appropriative Water Rights and the Efficient Allocation of Resources," *American Economic Review*, 1979, *69* (1), 25–37.

Burt, Oscar R., "Optimal Resource Use Over Time with an Application to Ground Water," *Management Science*, September 1964, *11* (1), 80–93.

Butsic, Van and Noelwah R. Netusil, "Valuing Water Rights in Douglas County, Oregon, Using the Hedonic Price Method," *Journal of the American Water Resources Association*, June 2007, *43* (3), 622–629.

Ciriacy-Wantrup, S. V., "Concepts Used as Economic Criteria for a System of Water Rights," *Land Economics*, 1956, *32* (4), 295–312.

Coman, Katharine, "Some unsettled problems of irrigation," *American Economic Review*, 1911, *1* (1), 1–19.

Connor, Jeffery D, Kurt Schwabe, Darran King, and Keith Knapp, "Irrigated agriculture and climate change: the influence of water supply variability and salinity on adaptation," *Ecological Economics*, 2012, *77*, 149–157.

Crouter, Jan P, "Hedonic Estimation Applied to a Water Rights Market," *Land Economics*, 1987, *63* (3), 259–271.

Deschenes, O. and M. Greenstone, "The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather," *American Economic Review*, 2007, *97* (1), 354–385.

Diao, Xinshen, Ariel Dinar, Terry Roe, and Yacov Tsur, "A general equilibrium analysis of conjunctive ground and surface water use with an application to Morocco," *Agricultural Economics*, March 2008, *38* (2), 117–135.

Diewert, WE, "Duality approaches to Microeconomic Theory," in K.J. Arrow and M.D. Intrilligator, eds., *Handbook of Mathematical Economics*, 1978.

Durlauf, Steven N, Andros Kourtellos, and Chih Ming Tan, "Is God in the details? A reexamination of the role of religion in economic growth," *Journal of Applied Econometrics*, 2012, *27* (7), 1059–1075.

Faux, John and Gregory M. Perry, "Estimating Irrigation Water Value Using Hedonic Price Analysis: A Case Study in Malheur County, Oregon," *Land Economics*, August 1999, *75* (3), 440–452.

Feldkircher, Martin and Stefan Zeugner, *Benchmark Priors Revisited: on Adaptive Shrinkage and the Supermodel Effect in Bayesian Model Averaging* number 9-202, International Monetary Fund, 2009.

Fisher, Anthony C., W. Michael Hanemann, Michael J. Roberts, and Wolfram Schlenker, "The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather: Comment," *American Economic Review*, 2012, *102* (7), 3749–3760.

George, Edward I et al., "Dilution priors: Compensating for model space redundancy," in "Borrowing Strength: Theory Powering Applications–A Festschrift for Lawrence D. Brown," Institute of Mathematical Statistics, 2010, pp. 158–165.

Geweke, J, "Evaluating the Accuracy of Sampling-Based Approaches to the Calculation of Posterior Moments," in J.M . Bernardo, J.O. Berger, A.P. Dowd, and A.F.M. Smith, eds., *Bayesian Statistics*, 4 ed., Oxford Universit, 1992.

Goldstein, Markus and Christopher Udry, "The Profits of Power : Land Rights and Agricultural Investment in Ghana," *Journal of Political Economy*, 2008, *116* (6), 981–1022.

Hanna, Rema, Esther Duflo, and Michael Greenstone, "Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves," *American Economic Journal: Economic Policy*, 2016, *8* (1), 80–114.

Hansen, Zeynep K, Gary D Libecap, and Scott E Lowe, "Climate Variability and Water Infrastructure: Historical Experience in the Western United States," in "The Economics of Climate Change: Adaptations Past and Present," University of Chicago Press, 2011, pp. 253–280.

Hausman, Jerry A and William E Taylor, "Panel data and unobservable individual effects," *Econometrica: Journal of the Econometric Society*, 1981, pp. 1377–1398.

Koop, Gary, *Bayesian Econometrics*, West Sussex: Wiley, 2003.

Kuminoff, Nicolai V., Christopher F. Parmeter, and Jaren C. Pope, "Which hedonic models can we trust to recover the marginal willingness to pay for environmental amenities?," *Journal of Environmental Economics and Management*, 2010, *60* (3), 145–160.

Libecap, Gary D., "Institutional Path Dependence in Climate Adaptation: Comans Some Unsettled Problems of Irrigation," *American Economic Review*, 2011, *101* (February), 64–80.

Markowitz, Harry M, *Portfolio selection: efficient diversification of investments*, Vol. 16, Yale University Press, 1968.

_ , "Foundations of portfolio theory," *Journal of Finance*, 1991, pp. 469–477.

Mendelsohn, Robert and Ariel Dinar, "Climate, Water, and Agriculture," *Land Economics*, August 2003, *79* (3), 328.

_ , William D Nordhaus, and Daigee Shaw, "The Impact of Global Warming on Agriculture: A Ricardian Analysis," *American Economic Review*, 1994, *84* (4), 753–771.

Moser, Mathias and Paul Hofmarcher, "Model Priors Revisited: Interaction Terms in BMA Growth Applications," *Journal of Applied Econometrics*, 2014, *29* (2), 344–347.

Mukherjee, Monobina and Kurt Schwabe, "Irrigated Agricultural Adaptation to Water and Climate Variability: The Economic Value of a Water Portfolio," *American Journal of Agricultural Economics*, 2015, *97* (3), 809–832.

NASS, "National Agricultural Statistics Service Cropland Data Layer," Technical Report, National Agricultural Statistics Service , United States Department of Agriculture 2006-2010. Available at http://nassgeodata.gmu.edu/CropScape. Accessed 6/17/2011.

Netusil, Noelwah R. and Matthew T. Summers, "Valuing instream flows using the hedonic price method," *Water Resources Research*, November 2009, *45* (W11429), 1–7.

NRCS, "Web Soil Survey," Technical Report, Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture 2009. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed 7/19/2013.

Olen, Beau, JunJie Wu, and Christian Langpap, "Irrigation Decisions for Major West Coast Crops: Water Scarcity and Climatic Determinants," *American Journal of Agricultural Economics*, 2016, *98* (1), 254–275.

Palmquist, Raymond B, "Land as a Differentiated Factor of Production: A Hedonic Model and Its Implications for Welfare Measurement," *Land Economics*, 1989, *65* (1), 23–28.

_ **and Leon E Danielson**, "A Hedonic Study of the Effects of Erosion Control and Drainage on Farmland Values," *American Journal of Agricultural Economics*, 1989, *71* (1), 55–62.

Petrie, Ragan A and Laura O Taylor, "Estimating the Value of Water Use Permits: A Hedonic Approach Applied to Farmland in the Southeastern United States," *Land Economics*, 2007, *83* (3), 302–318.

Raftery, Adrian E and Steven Lewis, "How Many Iterations in the Gibbs Sampler?," in J.M. Bernardo, J.O. Berger, A.P. Dowd, and A.F.M. Smith, eds., *Bayesian Statistics*, 4 ed., Oxford University Press, 1992.

_ **, David Madigan, and Jennifer A Hoeting**, "Bayesian Model Averaging for Linear Regression Models," *Journal of the American Statisitical Association*, 1997, *92* (437), 179–191.

Rosen, Sherwin, "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition," *Journal of Political Economy*, January 1974, *82* (1), 34.

Schlenker, W., W.M. Hanemann, and A.C. Fisher, "Will US agriculture really benefit from global warming? Accounting for irrigation in the hedonic approach," *American Economic Review*, 2005, *95* (1), 395–406.

Schlenker, Wolfram, W. Michael Hanemann, and Anthony C. Fisher, "Water Availability, Degree Days, and the Potential Impact of Climate Change on Irrigated Agriculture in California," *Climatic Change*, January 2007, *81* (1), 19–38.

Tsur, Yacov and Theodore Graham-Tomasi, "The buffer value of groundwater with stochastic surface water supplies," *Journal of Environmental Economics and Management*, November 1991, *21* (3), 201–224.

USBR, "Interim Comprehensive Basin Operating Plan," Technical Report, United States Bureau of Reclamation, Yakima Field Office, Yakima, WA 2002.

_ , "Yakima River Basin Study - Proposed Integrated Water Resource Management Plan Volume 1," Technical Report, United States Bureau of Reclamation; Washington State Department of Ecology, Yakima, WA 2011.

_ , "Yakima River Basin Study - Water Needs for Out-of-Stream Uses," Technical Report, United States Bureau of Reclamation, Yakima, WA 2011.

Vano, Julie A., Michael J. Scott, Nathalie Voisin, Claudio O. Stöckle, Alan F. Hamlet, Kristian E. B. Mickelson, Marketa McGuire Elsner, and Dennis P. Lettenmaier, "Climate change impacts on water management and irrigated agriculture in the Yakima River Basin, Washington, USA," *Climatic Change*, May 2010, *102* (1-2), 287–317.

Western Region Climate Center, "Monthly Climate Summaries," 2010.

Xu, Feng, Ron C. Mittlehammer, and L. Allen Torrell, "Modeling nonnegativity via truncated logistic and normal distributions: an application to ranch land price analysis," *Journal of Agricultural and Resource Economics*, 1994, *19* (1), 102–114.

Yakima County Superior Court, "Draft Schedule of Rights: Acquavella Surface Water Rights Adjudication," Technical Report 17, Yakima County Superior Court, Yakima, WA 2012.

Yoder, Jon, Jennifer Adam, Michael Brady, Joseph Cook, Stephen Katz, Daniel Brent, Shane Johnston, Keyvan Malek, and Qingqing Yang, "Benefit-Cost Analysis of the Yakima Basin Integrated Plan Projects," 2014.

Tables

Table 1: Characteristics of Irrigation Districts

District	County	% Senior	Senior Designation	Price	Acres	Observations
Buena	Yakima	100	Yes	5795	17	6
Cascade	Kittitas	100	Yes	9323	34	52
Columbia	Benton	100	Yes	7388	19	27
Ellensburg Water	Kittitas	100	Yes	10499	40	37
Kennewick	Benton	8	No	6831	40	178
Kittitas Reclamation	Kittitas	7	No	8673	28	455
Moxee-Selah	Yakima	86	Yes	7546	40	16
Naches-Selah	Yakima	91	Yes	7425	35	32
Olsen	Kittitas	100	Yes	7172	54	5
Roza	Yakima	0	No	7470	58	461
Sunnyside Valley	Yakima	73	Yes	7112	34	637
Union Gap	Yakima	79	Yes	7626	29	19
Wenas	Yakima	0	No	9455	28	14
West Side	Kittitas	76	Yes	9310	22	19
Yakima-Tieton	Yakima	65	Yes	6705	32	171
Yakima-Wapato	Yakima	49	No	4026	58	263

Notes: Roza and Sunnyside Valley are primarily in Yakima County but have some parcels in Benton County.

Table 2: Crops within Irrigation Districts

District	Pasture	Hay	Other Land	Developed	Grains	Orchard	Other Crops
Buena	0.33	0.50	0.00	0.00	0.00	0.17	0.00
Cascade	0.44	0.48	0.02	0.06	0.00	0.00	0.00
Columbia	0.15	0.19	0.44	0.07	0.15	0.00	0.00
Ellensburg Water	0.27	0.54	0.05	0.08	0.05	0.00	0.00
Kennewick	0.10	0.10	0.48	0.12	0.13	0.08	0.01
Kittitas Reclamation	0.54	0.18	0.23	0.03	0.02	0.00	0.00
Moxee-Selah	0.25	0.25	0.38	0.00	0.06	0.06	0.00
Naches-Selah	0.25	0.00	0.28	0.03	0.00	0.44	0.00
Olsen	0.40	0.40	0.00	0.20	0.00	0.00	0.00
Roza	0.08	0.13	0.14	0.07	0.11	0.44	0.03
Sunnyside Valley	0.04	0.15	0.17	0.20	0.16	0.25	0.03
Union Gap	0.05	0.11	0.26	0.05	0.00	0.53	0.00
Wenas	0.50	0.00	0.43	0.07	0.00	0.00	0.00
West Side	0.53	0.26	0.05	0.11	0.05	0.00	0.00
Yakima-Tieton	0.32	0.02	0.25	0.01	0.02	0.38	0.00
Yakima-Wapato	0.25	0.14	0.34	0.05	0.13	0.06	0.02

Notes: The columns show the proportion of parcels with a specified primary crop within each irrigation district.

Table 3: Data Description

Variable	Unit	Description
Price-per-acre	2008 USD	Dollar value agricultural sales divided by acres sold
Senior Water Right (Sr)	Binary	Dummy variable equal to one if a parcel lies within an irrigation district with more than 50% senior water rights
Percent Senior Water Right	%	Percentage of senior rights held by an irrigation district
Supplemental Right	Binary	Dummy variable equal to one if a property has any supplemental (groundwater) water rights in addition to rights from the irrigation district
Residential	Binary	Dummy variable equal to one if there are any residential structures on the property
Reservation	Binary	Dummy variable equal to one if the property is within the Yakima Nation Reservation
Improvements-per-acre	2008 USD	This is the dollar value of infrastructure improvements to the parcel since the last sale
Acres	Acres	Total acres of parcel sold
Rolling Avg	2008 USD	The rolling average of all sales from the previous twelve months normalized to 2008 USD
Soil Class 1-3	%	The percentage of soil in each of three soil classifications where the classification determines the suitability of the land for agriculture; lower classes are more suited to agriculture, the best class being Class 1 and the worst being Class 3. Class 3 contains all classes not in 1 or 2.
Soil Productivity	Index (0-100)	Designates the soil productivity due to soil quality
Distance to City	Miles	Distance of the parcel centroid to the nearest major city
Distance to UGA	Miles	Distance of the parcel centroid to the nearest urban growth area
Distance to Stream	Miles	Distance of the parcel centroid to the nearest major stream
Distance to River	Miles	Distance of the parcel centroid to the Yakima River
Kittitas	Binary	Dummy variable equal to one if the parcel is in Kittitas County
Benton	Binary	Dummy variable equal to one if the parcel is in Benton County
Primary Crop	Binary	Dummy variable for each of 7 crop categories
Secondary Crop	Binary	Dummy variable for each of 7 crop categories
Total Water Supply Available (TWSA)	Standardized	5-year rolling average of the surface water supply available to the Yakima Basin as calculated by the USBR normalized by the TWSA standard deviation
TWSA Deviation	Standardized	Negative deviations from long-run average of TWSA normalized by the TWSA standard deviation
Prorate	%	Percentage of entitlements that districts receive during the irrigation season; set based on the TWSA determined by the USBR

Notes: These are descriptions of all of the variables that were deemed important from the Bayesian Model Averaging and thus included in all regression models.

Table 4: Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
Price-per-acre	2,392	7,231.27	6,078.05	516.61	29,971.83
Senior	2,392	0.43	0.49	0	1
Percent Senior	2,392	0.40	0.35	0.00	1.00
Supplemental Rights	2,392	0.08	0.27	0	1
Residential	2,392	0.27	0.44	0	1
Yakima Reservation	2,392	0.11	0.31	0	1
Improvements per-acre	2,392	3,838.55	5,331.00	0.00	29,755.95
Acres	2,392	40.43	50.13	1.00	680.41
Slope	2,392	6.07	7.02	0.92	55.00
Soil Class 1	2,392	0.35	0.38	0.00	1.00
Soil Class 2	2,392	0.31	0.35	0.00	1.00
Soil Class 3	2,392	0.34	0.38	0.00	1.00
Soil Productivity	2,392	93.39	10.94	35.00	100.00
Distance to City	2,392	16.53	9.73	1.41	41.86
Distance to Stream	2,392	1.62	1.39	0.00	6.84
Kittitas	2,392	0.24	0.43	0	1
Benton	2,392	0.28	0.45	0	1
TWSA	2,392	5.20	0.55	4.28	6.41
TWSA Deviation	2,392	0.44	0.75	0.00	2.24

Table 5: BMA Regression - Water Rights

	Posterior Mean	Posterior Std. Dev.	PIP
	No Fixed Regressors		
Sr	-0.0011	0.0264	0.02
Sr Percent	0.0013	0.0325	0.01
Groundwater	0.0113	0.0391	0.09
	Fixed Sr & Groundwater		
Sr	0.0042	0.0548	1.00
Groundwater	0.1220	0.0568	1.00
	Fixed Sr Percent & Groundwater		
Sr Percent	0.0304	0.0619	1.00
Groundwater	0.1257	0.0564	1.00
Observations	2392		
Candidate Regressors	57		

Note: Coefficients are weighted by the posterior odds probability and are zero when covariates do not appear in a model. Posterior means and standard deviations are the based on 250,000 initial draws were taken with 50,000 burn-ins. PIP is the posterior inclusion probability.

Table 6: Hausman-Taylor Estimates

(a) Primary Results

	Estimate	Std. Error	t value	Pr(>|t|)
Senior	0.041	0.077	0.532	0.595
Groundwater	0.096	0.056	1.720	0.086

(b) Pseudo-Hausman Results

	Estimate	Std. Error	t value	Pr(¿—t—)
$\widehat{\text{Dist Stream}}$	0.485	0.849	0.571	0.568
$\widehat{\text{Dist Stream}^2}$	-0.361	0.518	-0.697	0.486
$\widehat{\text{Dist Stream}^3}$	0.066	0.089	0.738	0.460
$\widehat{\text{Dist City}}$	0.004	0.020	0.228	0.820
$\widehat{\text{Groundwater}}$	-0.792	1.404	-0.564	0.573

Note: Primary Hausman-Taylor estimates are based on the district fixed effects model for Groundwater and the two-stage IV model for Senior Dummy. The Pseudo-Hausman results show coefficients for the relevant within-transformed variables in the auxiliary OLS regression to assess the validity of instruments.

Table 7: Boundary Discontinuity Specification Tests

(a) Averages by Subsample

Sample	% Senior	Price	Acres	Primary Crop	Groundwater	Improvements	Residential	Slope	Year	N
Full	0.40	7231	40	Other Land	0.08	3839	0.27	6.1	2003	2392
5-Mile	0.39	7474	40	Pasture	0.08	4030	0.25	5.8	2003	1988
4-Mile	0.39	7605	40	Orchard	0.08	3996	0.24	5.8	2003	1843
3-Mile	0.39	7660	40	Orchard	0.08	3977	0.24	5.9	2003	1613
2-Mile	0.39	7767	39	Orchard	0.07	3984	0.23	6.1	2003	1274
1-Mile	0.43	7992	38	Orchard	0.08	3951	0.22	6.7	2004	780

(b) Differences in Subsamples: F-test

Dependent Variable	F-stat	p-value
Price	45.368	0.000
Acres	2.405	0.121
Right	1.700	0.192
Improvements	15.182	0.000
Year of Sale	3.641	0.056
% Senior	0.012	0.913
Slope	2.342	0.126
Orchard	2.839	0.092

(c) Differences in Coefficients: Interaction-test

	F-stat	p-value
1-Mile	1.11	0.29
2-Mile	0.72	0.40
3-Mile	1.27	0.26
4-Mile	0.04	0.85
5-Mile	0.04	0.57

Note: Panel (a) is a set of means by each buffer subsample. Panel (b) performs an F-test for joint significance of the dummy variables representing each buffer subsample on the variables defined in the first column. Panel (c) performs an F-test of joint significance on the interaction terms of all variables in the base regression with a dummy for each buffer subsample.

Table 8: Boundary Discontinuity Posterior Estimates

	Mean	Std. Dev.	N
Full Sample	0.081	0.036	2392
1 Mile	0.044	0.060	780
2 Mile	0.026	0.048	1274
3 Mile	0.009	0.044	1613
4 Mile	0.017	0.041	1843
5 Mile	0.043	0.040	1988

Note: These are estimates of the posterior distribution for the senior right coefficient with all controls for the base regression except for the reservation dummy. Posterior distributions are based on 30,000 draws in the Gibbs sampler with 100,000 burn-ins. Buffers are defined as parcels within that overlap within 1-5 miles from the irrigation district boundaries.

Table 9: Robustness for Aggregate Senior Premium

	(1) Base	(2) No Developed	(3) No Residential	(4) Price	(5) Acres	(6) Year	(7) County*Time	(8) County*Roll
Senior	0.049	0.059	0.045	0.042	0.051	0.039	0.023	0.021
	[-0.03, 0.13]	[-0.03, 0.14]	[-0.06, 0.14]	[-0.02, 0.11]	[-0.04, 0.14]	[-0.04, 0.12]	[-0.06, 0.1]	[-0.06, 0.1]
Groundwater	0.134	0.157	0.182	0.067	0.19	0.125	0.099	0.111
	[0.03, 0.24]	[0.04, 0.26]	[0.05, 0.32]	[-0.02, 0.16]	[0.07, 0.31]	[0.02, 0.23]	[-0.01, 0.2]	[0, 0.22]
Observations	2392	2168	1621	1912	1911	2392	2392	2392

Note: The rows display estimates of the posterior means with the 95% HPD interval underneath.The columns represent different regression models.

Table 10: Regressions Incorporating Water Supply

	(1) Deliveries	(2) Deliveries, Sr	(3) Deliveries, FE	(4) TWSA*Sr
Deliveries	-0.02	-0.019	-0.07	
	[-0.05, 0.01]	[-0.05, 0.01]	[-0.12, -0.03]	
TWSA Rolling Avg	0.054	0.054	0.062	0.049
	[-0.02, 0.13]	[-0.02, 0.13]	[-0.02, 0.14]	[-0.03, 0.13]
TWSA Deviations	-0.052	-0.053	-0.092	-0.006
	[-0.11, 0]	[-0.1, 0]	[-0.15, -0.03]	[-0.06, 0.05]
Senior Dummy		0.047		0.078
		[-0.03, 0.13]		[-0.01, 0.17]
Senior*TWSA Dev.				-0.064
				[-0.14, 0.01]
Observations	2392	2392	2392	2392

Note: The rows display estimates of the posterior means with the 95% HPD interval underneath. The columns represent different regression models.

Table 11: Heterogeneity In Senior Premium

	(1) Base	(2) Right	(3) Orchard	(4) Right & Orchard
Senior	0.049	0.066	0.08	0.096
	[-0.033, 0.131]	[-0.019, 0.15]	[-0.006, 0.169]	[0.006, 0.187]
Groundwater	0.134	0.2	0.128	0.193
	[0.026, 0.242]	[0.066, 0.333]	[0.017, 0.233]	[0.055, 0.323]
Orchard	0.22	0.22	0.295	0.292
	[0.141, 0.299]	[0.14, 0.297]	[0.185, 0.403]	[0.184, 0.401]
Sr*Groundwater		-0.183		-0.176
		[-0.399, 0.036]		[-0.397, 0.038]
Sr*Orchard			-0.141	-0.137
			[-0.285, 0.005]	[-0.281, 0.005]
Observations	2392	2392	2392	2392

Note: The rows display estimates of the posterior means with the 95% HPD interval underneath.The columns represent different regression models.

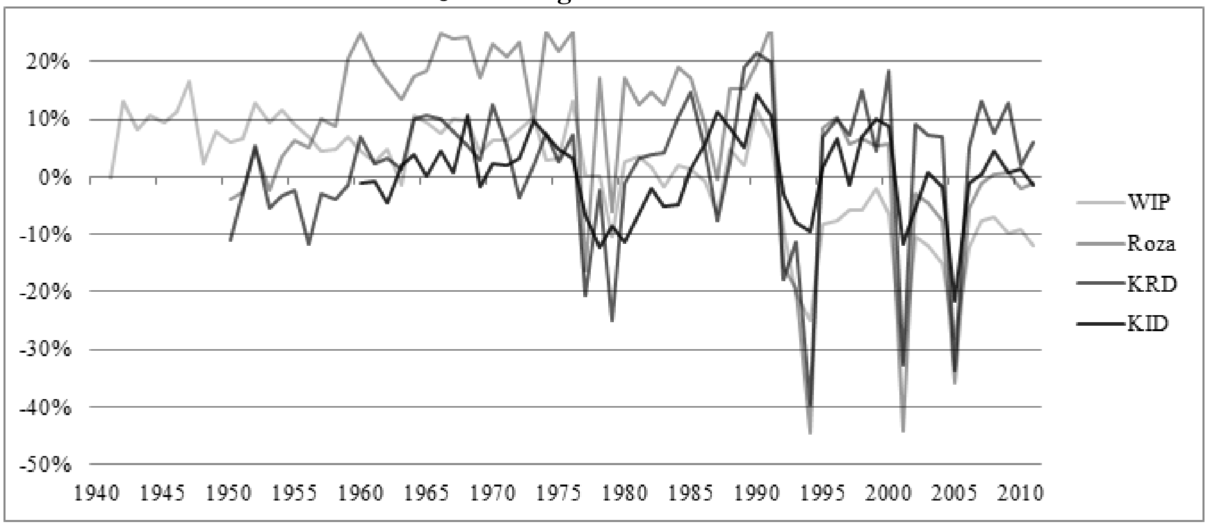
Table 12: Confidence Intervals for Irrigation Benefits

	Lower 95%	Upper 95%
Aggregate (BMA)	-150,893,507	163,099,147
Aggregagte (Base)	-46,580,548	202,594,079
Hausman-Taylor	-161,327,526	281,644,914

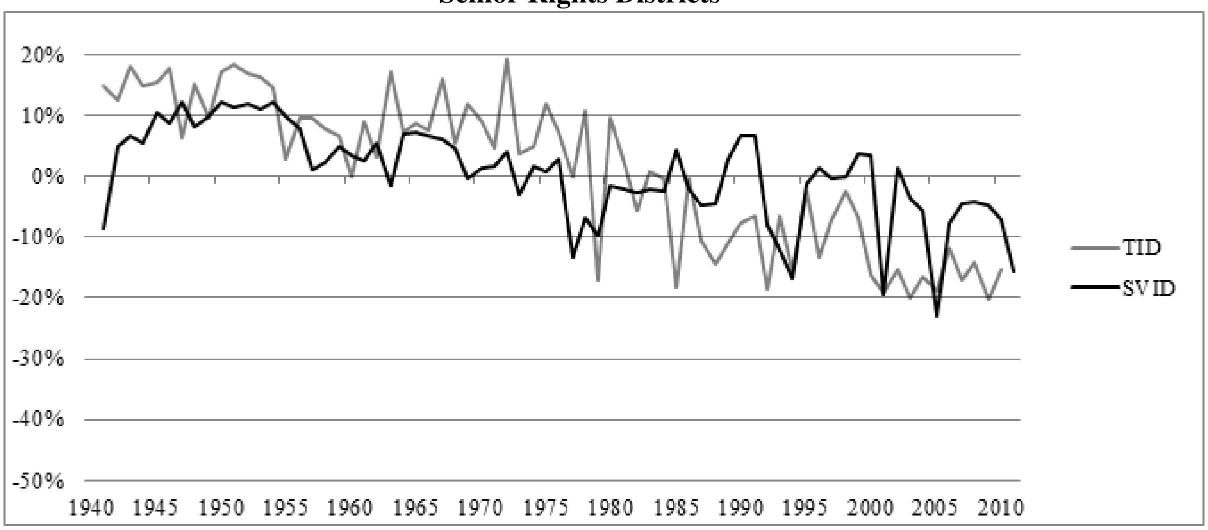
Note: The confidence intervals are derived from parameters of the posterior distribution for the senior water right dummy. Estimates are scaled by using acreage of agricultural land with junior water rights in the Yakima Basin and the average real price of agricultural land in 2008 dollars.

Figures

Junior Rights Districts

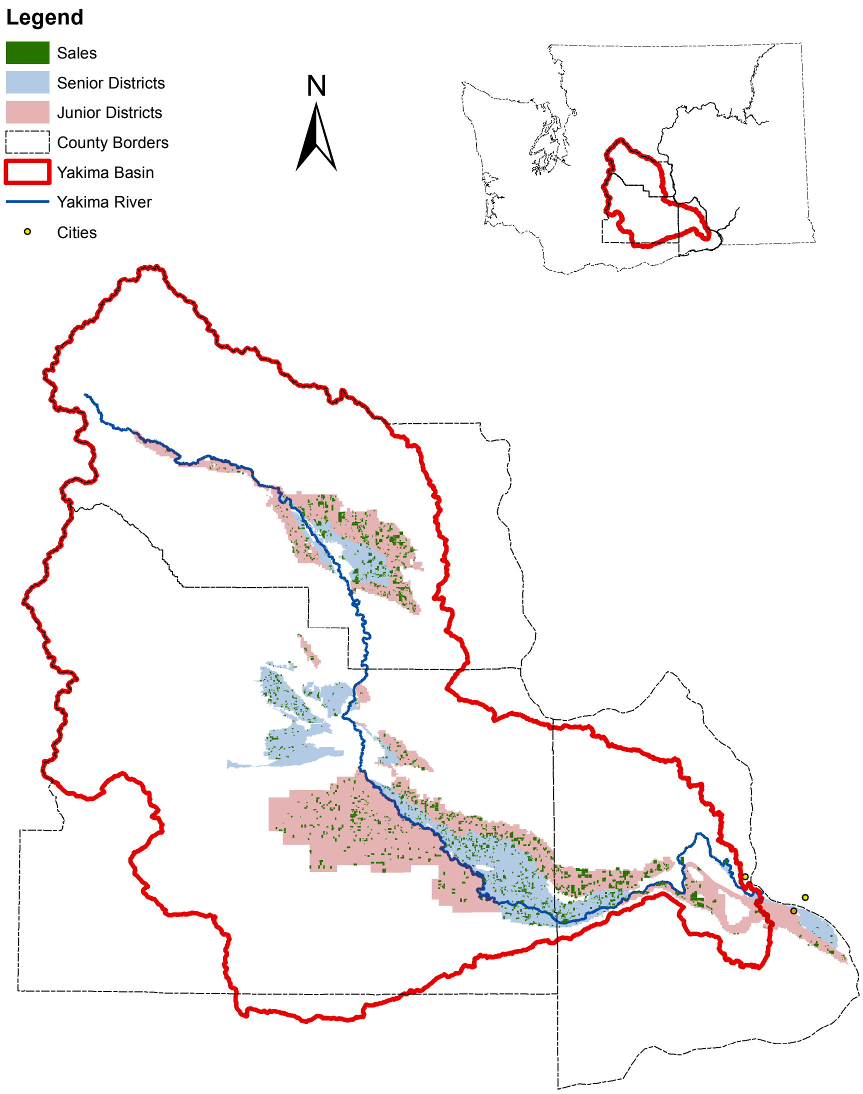


Senior Rights Districts



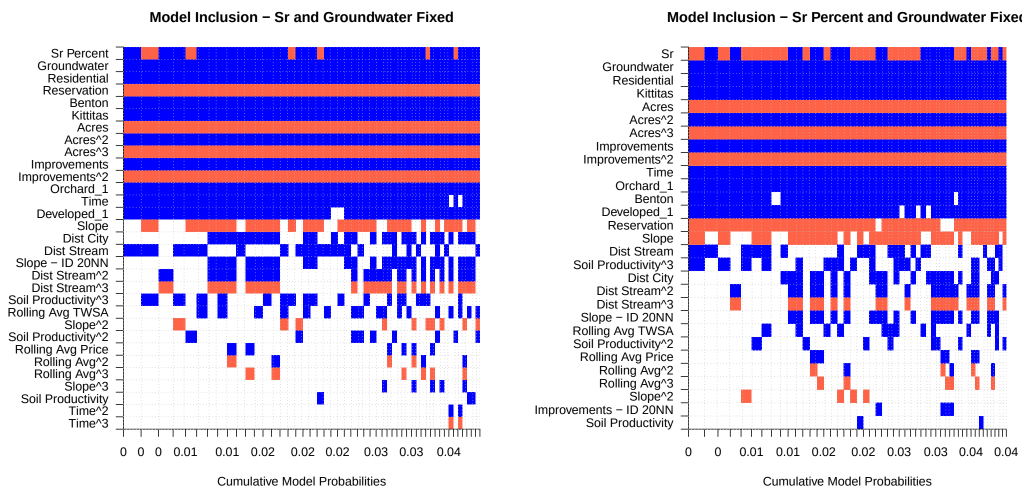
Note: Annual deviations from the mean are shown in percentage terms by irrigation district. TID and SVID are identified as senior district while KRD, Roza and WIP are junior districts based on the Integrated Plan (USBR 2012). Even though KID owns predominantly junior rights it receives recharge water from withdrawals upstream and is therefore less susceptible to droughts. Data are from USBR via Chris Lynch.

Figure 1: Annual Deviations from Mean Diversions by District



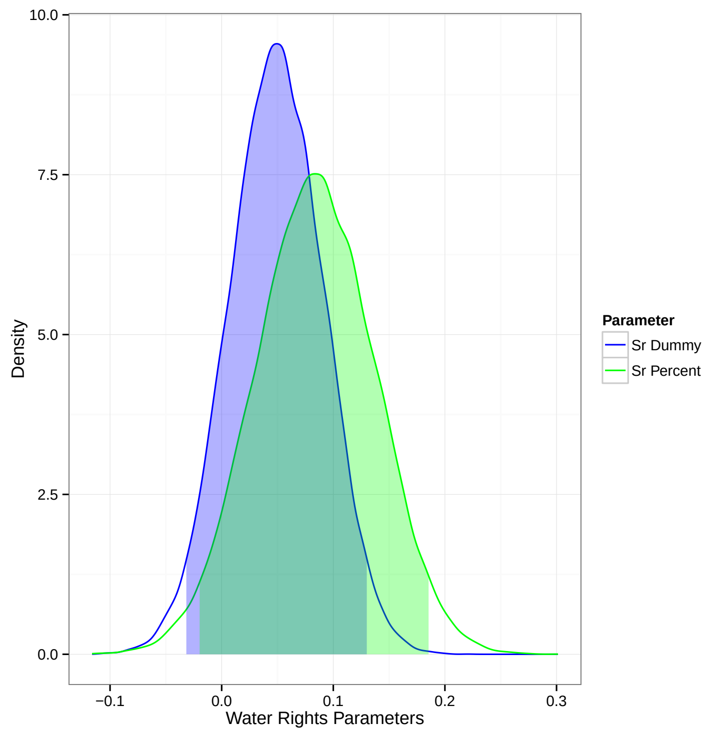
Note: This map shows the irrigation districts designated by water right seniority and agricultural property sales.

Figure 2: Map of Yakima Basin Irrigation Districts and Agricultural Sales



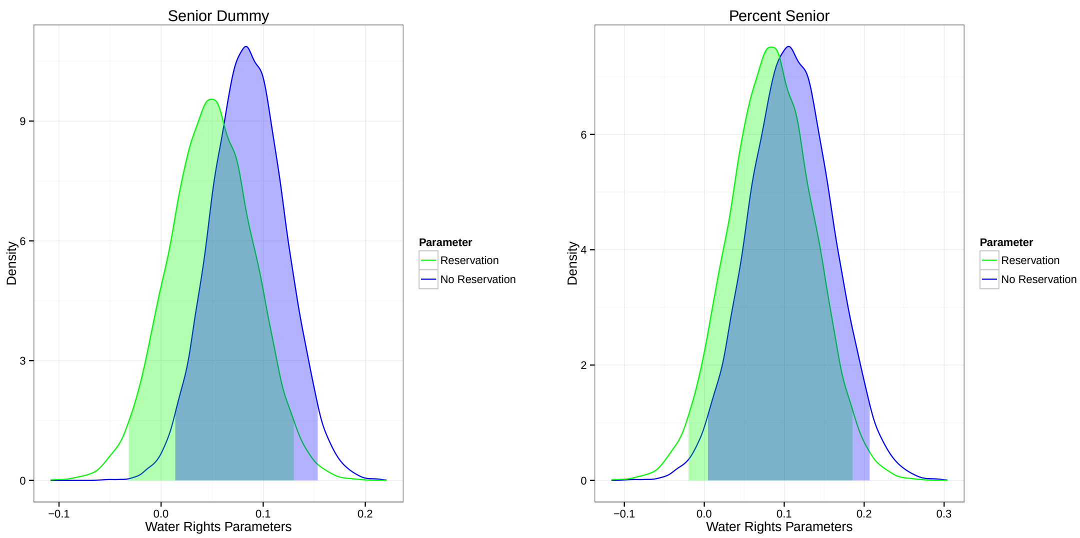
Note: Models include the top 50 models based on posterior odds. When a variable is present in a given model it is colored blue when greater than zero and red when less than zero. The width of each model represents the cumulative model probabilities shown on the x axis.

Figure 3: BMA Model Selection



Note: This is the posterior distribution for the senior water right coefficient in the base regression. Additional controls are shown in Tables A.2 and A.3 in the Appendix. Posterior distributions are based on 30,000 draws in the Gibbs sampler with 100,000 burn-ins. The shaded areas represent the 95% highest posterior density interval.

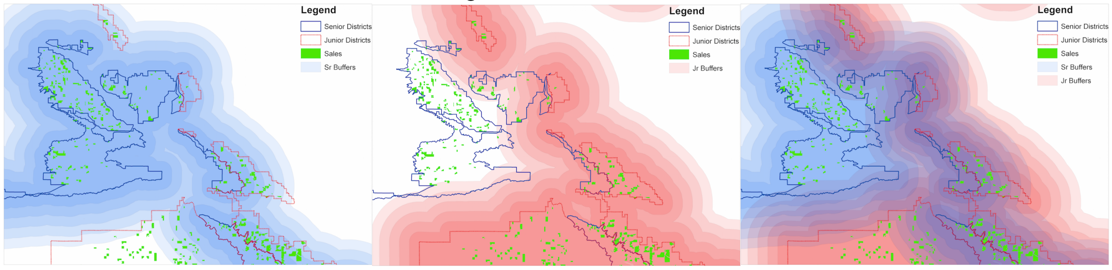
Figure 4: Posterior Distributions for Senior Rights



Note: This is the posterior distribution for the senior water right coefficients in the base regression excluding Yakima Nation Reservation dummy. Posterior distributions are based on 30,000 draws in the Gibbs sampler with 100,000 burn-ins. The shaded areas represent the 95% highest posterior density interval.

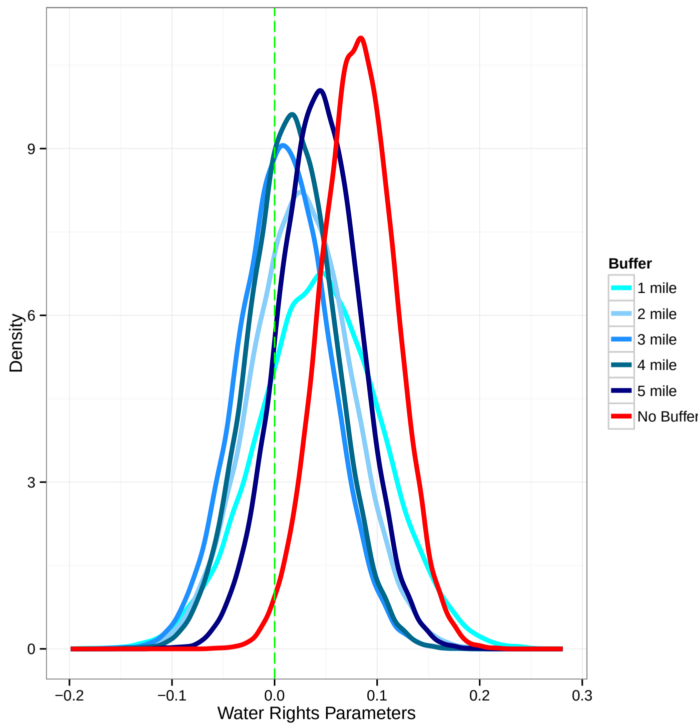
Figure 5: Impact of Yakima Nation Reservation on Value of Senior Rights

Senior Buffers | Junior Buffers | Both Buffers



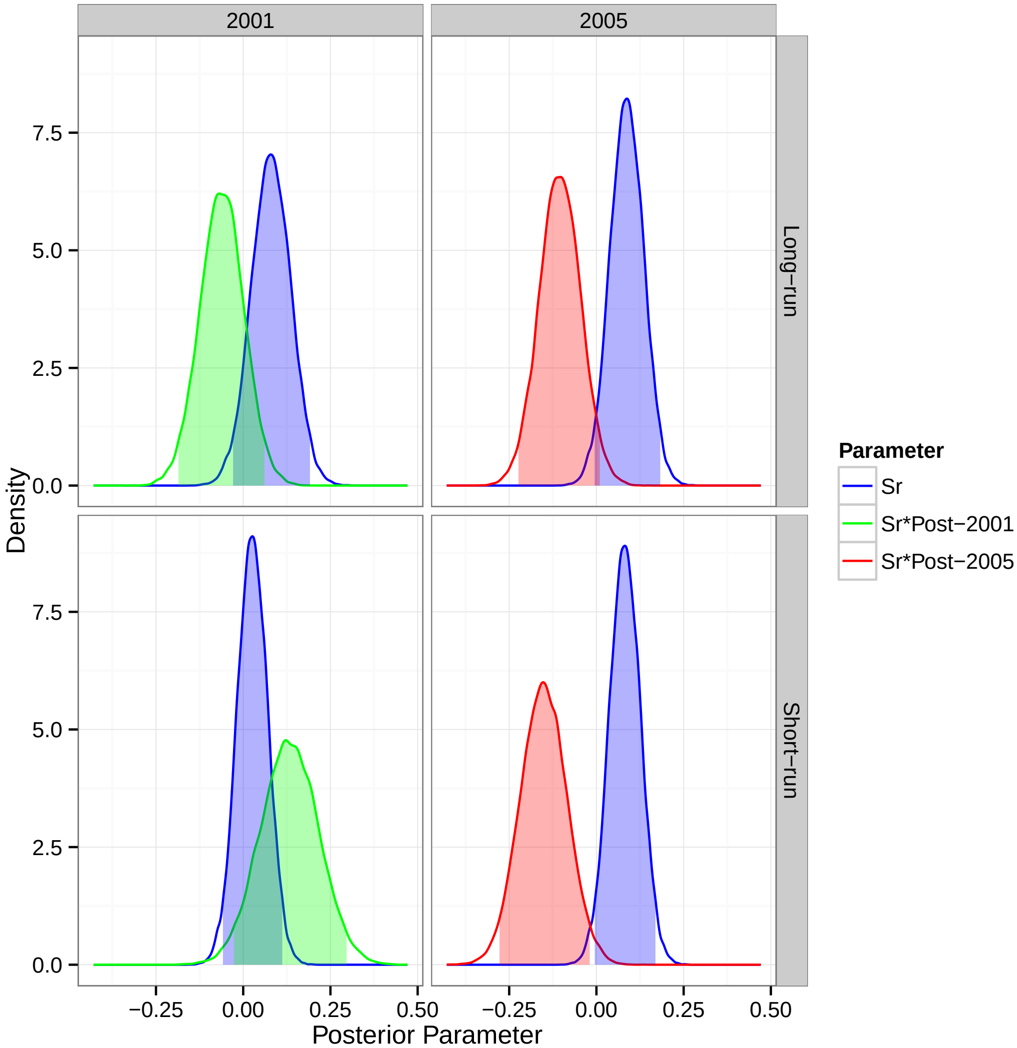
Note: The maps highlights one area of the boundary discontinuity design. The maps contain only the senior buffer, only the junior buffers and then both buffers together. The darkest buffer represents 1 mile and the lightest is 5 miles. The buffer subsamples are created when the corresponding junior and senior buffers overlap.

Figure 6: Boundary Discontinuity Design: 1-5 Mile Buffers



Note: This is the posterior distribution for the senior right coefficient with all controls for the base regression except for the reservation dummy. Posterior distributions are based on 30,000 draws in the Gibbs sampler with 100,000 burn-ins. Buffers are defined as parcels within that overlap within 1-5 miles from the irrigation district boundaries.

Figure 7: Boundary Discontinuity Results - Senior Posterior



Note: This is the posterior distribution for the senior right coefficient with all controls in the Base regression. Posterior distributions are based on 30,000 draws in the Gibbs sampler with 100,000 burn-ins. The colors of the distributions designate samples before and after the 2001 and 2005 droughts respectively. The shaded areas represent the 95% highest posterior density intervals.

Figure 8: Posterior Distributions for Senior Rights by Drought

A Bayesian Model Averaging

Table A.1: Bayesian Model Averaging

	Posterior Mean	Posterior Std. Dev.	PIP
Acres	-0.0097	0.0011	1.00
Acres^2	0.0000	0.0000	1.00
Improvements	0.0001	0.0000	1.00
Orchard_1	0.2318	0.0430	1.00
Acres^3	-0.0000	0.0000	1.00
Residential	0.1869	0.0401	1.00
Kittitas	0.6034	0.1396	0.99
Reservation	-0.3612	0.1073	0.97
Improvements^2	-0.0000	0.0000	0.96
Time	0.0035	0.0009	0.95
Benton	0.1653	0.0708	0.90
Developed_1	0.1422	0.0930	0.76
Slope	-0.0042	0.0050	0.48
Dist Stream^2	0.0175	0.0236	0.46
Dist Stream^3	-0.0028	0.0037	0.43
Dist Stream	0.0127	0.0328	0.40
Slope - ID 20NN	0.0107	0.0152	0.38
Soil Productivity^3	0.0000	0.0000	0.32
Rolling Avg Price	1.3339	3.8025	0.29
Slope^2	-0.0001	0.0003	0.28
Rolling Avg^2	-0.0121	0.3813	0.27
Dist City	0.0016	0.0061	0.26
Rolling Avg TWSA	0.0201	0.0370	0.26
Rolling Avg^3	-0.0048	0.0164	0.25
Soil Productivity^2	-0.0000	0.0002	0.19
Improvements^3	0.0000	0.0000	0.16
Soil Productivity	0.0013	0.0125	0.14
Slope^3	0.0000	0.0000	0.13
Orchard_2	0.0126	0.0394	0.11
Dist City^2	0.0001	0.0004	0.10
Groundwater	0.0113	0.0391	0.09
Residential - ID 20NN	-0.0547	0.2038	0.09
Dist UGA^3	0.0000	0.0001	0.08
Improvements - ID 20NN	0.0000	0.0000	0.08
Pasture_2	-0.0077	0.0291	0.08
Time^3	-0.0000	0.0000	0.07
Dist UGA^2	0.0002	0.0011	0.06
Time^2	0.0000	0.0000	0.06
Deviation TWSA	-0.0023	0.0111	0.06
Dist City^3	-0.0000	0.0000	0.06
Soil Class 3	-0.0056	0.0262	0.06
Dist River	0.0019	0.0099	0.05
Grains_2	0.0038	0.0197	0.05
Pasture_1	0.0031	0.0174	0.04
Dist River^3	-0.0000	0.0000	0.03
Dist River^2	-0.0001	0.0008	0.03
Grains_1	0.0025	0.0175	0.03
Dist UGA	0.0001	0.0038	0.02
Sr	-0.0011	0.0264	0.02
Acres - ID 20NN	-0.0000	0.0003	0.01
Soil Class 2	0.0003	0.0063	0.01
Hay_1	0.0003	0.0061	0.01
Sr Percent	0.0013	0.0325	0.01
Other Crops_2	-0.0003	0.0088	0.01
Developed_2	0.0001	0.0031	0.01
Other Crops_1	0.0005	0.0123	0.01
Hay_2	0.0001	0.0046	0.01
Observations	2392		
Candidate Regressors	57		
R^2	0.287		

Note: Coefficients are weighted by the posterior odds probability and are zero when covariates do not appear in a model. Posterior means and standard deviations are the based on 200,000 draws were taken with 50,000 burn-ins. PIP is the posterior inclusion probability.

B Regression Tables

Table A.2: Bayesian Regression - Senior Dummy

	Mean	Std. Dev.	Lower 95% CI	Upper 95% CI
Senior	0.04907	0.04167	-0.03241	0.12990
Groundwater	0.13428	0.05470	0.02635	0.24012
Residential	0.18998	0.03918	0.11307	0.26673
Reservation	-0.13875	0.08211	-0.30058	0.02240
Benton	0.23245	0.05893	0.11712	0.34967
Kittitas	0.65255	0.11996	0.41867	0.88721
Acres	-0.00991	0.00102	-0.01191	-0.00790
Acres^2	0.00004	0.00001	0.00003	0.00005
Acres^3	-0.00000	0.00000	-0.00000	-0.00000
Improvements	0.00006	0.00001	0.00004	0.00007
Improvements^2	-0.00000	0.00000	-0.00000	-0.00000
Rolling Avg TWSA	0.05247	0.03981	-0.02536	0.13047
Deviation TWSA	-0.03665	0.02303	-0.08185	0.00829
Time	0.00181	0.00323	-0.00454	0.00818
Time^2	0.00002	0.00003	-0.00004	0.00007
Time^3	-0.00000	0.00000	-0.00000	0.00000
Rolling Avg	27.51228	76.38455	-122.29040	177.98048
Rolling Avg^2	-2.77727	8.93140	-20.40450	14.70444
Rolling Avg^3	0.09155	0.34769	-0.58819	0.77638
Soil Productivity	0.20688	0.06981	0.06950	0.34259
Soil Productivity^2	-0.00293	0.00098	-0.00484	-0.00101
Soil Productivity^3	0.00001	0.00000	0.00000	0.00002
Slope	0.01215	0.01068	-0.00878	0.03315
Slope^2	-0.00188	0.00068	-0.00322	-0.00054
Slope^3	0.00003	0.00001	0.00001	0.00005
Dist Stream	-0.13322	0.06578	-0.26235	-0.00396
Dist Stream^2	0.10020	0.02966	0.04200	0.15856
Dist Stream^3	-0.01323	0.00356	-0.02023	-0.00624
Dist City	0.00984	0.00237	0.00526	0.01455
Residential - ID 20NN	-0.23068	0.23215	-0.68378	0.22584
Improvements - ID 20NN	0.00005	0.00002	0.00002	0.00009
Slope - ID 20NN	0.04023	0.00806	0.02456	0.05604
Orchard_1	0.22052	0.04000	0.14128	0.29868
Developed_1	0.19055	0.05267	0.08632	0.29301
σ^2	0.48023	0.01404	0.45313	0.50817
Observations	2392			
R^2	0.302			

Note: The dependent variable is the natural log of the per acre sale price of a parcel. These are moments of the posterior distribution for the senior rights coefficient with all controls in the Base regression. Posterior distributions are based on 30,000 draws in the Gibbs sampler with 100,000 burn-ins. Upper and Lower 95% CI are values for the 95% credible interval.

Table A.3: Bayesian Regression - Senior Percent

	Mean	Std. Dev.	Lower 95% CI	Upper 95% CI
Sr Percent	0.08360	0.05291	-0.02000	0.18620
Groundwater	0.13652	0.05469	0.02858	0.24231
Residential	0.18856	0.03919	0.11159	0.26532
Reservation	-0.16500	0.07228	-0.30777	-0.02352
Benton	0.23318	0.05856	0.11867	0.34968
Kittitas	0.64849	0.11961	0.41487	0.88300
Acres	-0.00986	0.00102	-0.01186	-0.00786
Acres^2	0.00004	0.00001	0.00003	0.00005
Acres^3	-0.00000	0.00000	-0.00000	-0.00000
Improvements	0.00006	0.00001	0.00004	0.00007
Improvements^2	-0.00000	0.00000	-0.00000	-0.00000
Rolling Avg TWSA	0.05268	0.03980	-0.02518	0.13059
Deviation TWSA	-0.03731	0.02303	-0.08250	0.00767
Time	0.00182	0.00323	-0.00452	0.00818
Time^2	0.00002	0.00003	-0.00004	0.00007
Time^3	-0.00000	0.00000	-0.00000	0.00000
Rolling Avg	26.59571	76.37159	-123.18735	177.03884
Rolling Avg^2	-2.67275	8.92985	-20.30037	14.80960
Rolling Avg^3	0.08759	0.34763	-0.59214	0.77226
Soil Productivity	0.20721	0.06977	0.07018	0.34298
Soil Productivity^2	-0.00294	0.00098	-0.00484	-0.00101
Soil Productivity^3	0.00001	0.00000	0.00000	0.00002
Slope	0.01336	0.01073	-0.00768	0.03441
Slope^2	-0.00194	0.00069	-0.00329	-0.00060
Slope^3	0.00003	0.00001	0.00001	0.00005
Dist Stream	-0.13280	0.06577	-0.26193	-0.00363
Dist Stream^2	0.10047	0.02963	0.04226	0.15880
Dist Stream^3	-0.01325	0.00356	-0.02026	-0.00627
Dist City	0.01006	0.00238	0.00546	0.01480
Residential - ID 20NN	-0.24182	0.23162	-0.69397	0.21334
Improvements - ID 20NN	0.00006	0.00002	0.00002	0.00009
Slope - ID 20NN	0.04050	0.00806	0.02484	0.05629
Orchard_1	0.22156	0.04000	0.14236	0.29978
Developed_1	0.19028	0.05264	0.08611	0.29272
σ^2	0.48001	0.01404	0.45292	0.50793
Observations	2392			
R^2	0.303			

Note: The dependent variable is the natural log of the per acre sale price of a parcel. These are moments of the posterior distribution for the senior rights coefficient with all controls in the Base regression. Posterior distributions are based on 30,000 draws in the Gibbs sampler with 100,000 burn-ins. Upper and Lower 95% CI are values for the 95% credible interval.

Table A.4: Senior Dummy and Time Interaction

	Mean	Std. Dev.	Lower 95% CI	Upper 95% CI
Senior	0.09113	0.07933	-0.06449	0.24680
Sr*Time	-0.00029	0.00046	-0.00120	0.00061

Note: The dependent variable is the natural log of the per acre sale price of a parcel. These are moments of the posterior distribution for the senior rights coefficient and an interaction with a linear time trend with all controls in the Base regression. Posterior distributions are based on 30,000 draws in the Gibbs sampler with 100,000 burn-ins. Upper and Lower 95% CI are values for the 95% credible interval.

Table A.5: Senior Dummy and Time Interaction (Quadratic)

	Mean	Std. Dev.	Lower 95% CI	Upper 95% CI
Senior	0.05039	0.12117	-0.18642	0.28821
Sr*Time	0.00052	0.00186	-0.00312	0.00415
Sr*Time^2	-0.00000	0.00001	-0.00002	0.00001

Note: The dependent variable is the natural log of the per acre sale price of a parcel. These are moments of the posterior distribution for the senior rights coefficient and an interaction with a linear and quadratic time trend with all controls in the Base regression. Posterior distributions are based on 30,000 draws in the Gibbs sampler with 100,000 burn-ins. Upper and Lower 95% CI are values for the 95% credible interval.

Table A.6: Percentage of Orchards by Senior and Groundwater Rights

Comparison	Mean without Right	Mean with Right	t-statistic	p-value
% Orchard by Senior	17.1	24.7	-4.506	0.000
% Orchard by Groundwater	19.4	30.9	-3.324	0.001
% Orchard by Groundwater (Senior Only)	24.6	26.5	-0.344	0.732
% Orchard by Groundwater (Junior Only)	15.5	33.3	-4.071	0.000

Note: The rows represent comparisons of the percentage of parcels that have orchard as the primary crop by senior and groundwater rights. The last two rows compare groundwater rights isolating the senior and junior sample. The sample percentage of orchards is 20%.

Table A.7: Robustness for Aggregate Senior Premium - 90% HPD

	(1) Base	(2) No Developed	(3) No Residential	(4) Price	(5) Acres	(6) Year	(7) County*Time	(8) County*Roll
Senior	0.049	0.059	0.045	0.042	0.051	0.039	0.023	0.021
	[-0.02, 0.12]	[-0.01, 0.13]	[-0.04, 0.13]	[-0.01, 0.1]	[-0.02, 0.12]	[-0.03, 0.11]	[-0.04, 0.09]	[-0.05, 0.09]
Groundwater	0.134	0.157	0.182	0.067	0.19	0.125	0.099	0.111
	[0.04, 0.22]	[0.06, 0.25]	[0.07, 0.29]	[-0.01, 0.14]	[0.09, 0.29]	[0.03, 0.21]	[0.01, 0.19]	[0.02, 0.2]
Observations	2392	2168	1621	1912	1911	2392	2392	2392

Note: The rows display estimates of the posterior means with the 90% HPD interval underneath.The columns represent different regression models.

Table A.8: Heterogeneity In Senior Premium - 90% HPD

	(1) Base	(2) Right	(3) Orchard	(4) Right & Orchard
Senior	0.049	0.066	0.08	0.096
	[-0.02, 0.118]	[-0.005, 0.137]	[0.005, 0.152]	[0.022, 0.174]
Groundwater	0.134	0.2	0.128	0.193
	[0.042, 0.223]	[0.088, 0.312]	[0.043, 0.225]	[0.083, 0.308]
Orchard	0.22	0.22	0.295	0.292
	[0.153, 0.286]	[0.156, 0.288]	[0.203, 0.387]	[0.199, 0.381]
Sr*Groundwater		-0.183		-0.176
		[-0.369, -0.001]		[-0.353, 0.011]
Sr*Orchard			-0.141	-0.137
			[-0.259, -0.016]	[-0.261, -0.019]
Observations	2392	2392	2392	2392

Note: The rows display estimates of the posterior means with the 90% HPD interval underneath.The columns represent different regression models.

C MCMC Convergence Diagnostics

The Gibbs sampler is an MCMC procedure where arbitrary initial values may bias the results. There are several diagnostic tools used to assess the convergence of the Gibbs sampler to the true joint posterior distribution, ensuring that the effect of the starting values has worn off. We employ three tools that all indicate that the Gibbs sampler reached convergence. The dependence factor, also known as the I-statistic, is the ratio of the number of draws required for given accuracy level to the number of draws necessary if the chain was i.i.d., developed by Raftery and Lewis (1992). Table A.9 shows that for an accuracy level of 0.5% the I-statistic for all parameters is around 1, which is the recommended level and safely below the recommended threshold of 5. Next I use the Geweke diagnostics Geweke (1992) which tests the equality in means for two regions of the Gibbs sampler. I use the first 20% and the last 50% of the MCMC draws. If the Gibbs sampler reached convergence then any subset should represent the true joint posterior and there should be no difference in parameter means for different regions. Table A.10 shows z-statistics and the associated p-values for the χ^2 test for the null of equal means. Almost every parameter has p-values well above the 10% level. Another set of diagnostics is the Heidelberger-Welch test for stationarity and the halfwidth test. These tests assess if the length of MCMC draws is sufficient for the distribution to be deemed stationary. Table A.11 shows that all parameters are determined to come from a stationary distribution and the halfwidth test shows that most are below the conventional halfwidth/mean ratio threshold of 0.1. Lastly I assess the autocorrelation of draws in the parameter chain, which is another metric to determine if the Gibbs sampler is drawing from the true distribution. The low level of serial correlation in the Gibbs draws as shown in Table A.12 provides evidence that the draws represent and independent sample. These diagnostics tool suggest that the Gibbs sampler has reached convergence; not a surprise given that running 40,000 draws with 100,000 burn-in draws is extremely circumspect.

Table A.9: Raftery-Lewis MCMC Diagnostics

	Burn-in (M)	Total (N)	Lower bound (Nmin)	Dependence factor (I)
Interpect	2	3710	3746	0.99
Senior	2	3730	3746	1.00
Groundwater	2	3781	3746	1.01
Residential	2	3720	3746	0.99
Reservation	2	3680	3746	0.98
Benton	2	3844	3746	1.03
Kittitas	2	3730	3746	1.00
Acres	2	3781	3746	1.01
Acres^2	2	3649	3746	0.97
Acres^3	2	3649	3746	0.97
Improvements	2	3730	3746	1.00
Improvements^2	2	3802	3746	1.01
Rolling Avg TWSA	2	3761	3746	1.00
Deviation TWSA	2	3771	3746	1.01
Time	2	3730	3746	1.00
Time^2	2	3761	3746	1.00
Time^3	2	3792	3746	1.01
Rolling Avg	2	3771	3746	1.01
Rolling Avg^2	2	3720	3746	0.99
Rolling Avg^3	2	3761	3746	1.00
Soil Productivity	1	3750	3746	1.00
Soil Productivity^2	2	3761	3746	1.00
Soil Productivity^3	2	3730	3746	1.00
Slope	2	3740	3746	1.00
Slope^2	2	3740	3746	1.00
Slope^3	2	3771	3746	1.01
Dist Stream	2	3680	3746	0.98
Dist Stream^2	2	3710	3746	0.99
Dist Stream^3	2	3740	3746	1.00
Dist City	2	3690	3746	0.98
Residential - ID 20NN	1	3750	3746	1.00
Improvements - ID 20NN	2	3844	3746	1.03
Slope - ID 20NN	2	3771	3746	1.01
Orchard_1	2	3771	3746	1.01
Developed_1	2	3700	3746	0.99
σ^2	2	3710	3746	0.99

Table A.10: Geweke MCMC Diagnostics

	Z-statistic	p-value
Interpect	-1.208	0.227
Senior	-0.752	0.452
Groundwater	-0.356	0.722
Residential	0.226	0.821
Reservation	-1.525	0.127
Benton	-0.208	0.835
Kittitas	-0.155	0.877
Acres	-1.361	0.174
Acres^2	1.679	0.093
Improvements	0.898	0.369
Rolling Avg TWSA	-1.318	0.188
Deviation TWSA	0.574	0.566
Time	0.360	0.719
Time^2	-0.504	0.614
Time^3	0.526	0.599
Rolling Avg	1.178	0.239
Rolling Avg^2	-1.155	0.248
Rolling Avg^3	1.134	0.257
Soil Productivity	1.015	0.310
Soil Productivity^2	-0.970	0.332
Soil Productivity^3	0.939	0.348
Slope	1.177	0.239
Slope^2	-1.802	0.072
Slope^3	1.902	0.057
Dist Stream	1.739	0.082
Dist Stream^2	-1.196	0.232
Dist Stream^3	0.702	0.483
Dist City	-0.108	0.914
Residential - ID 20NN	0.347	0.729
Improvements - ID 20NN	0.964	0.335
Slope - ID 20NN	-0.549	0.583
Orchard_1	-1.850	0.064
Developed_1	-1.135	0.256
σ^2	1.484	0.138

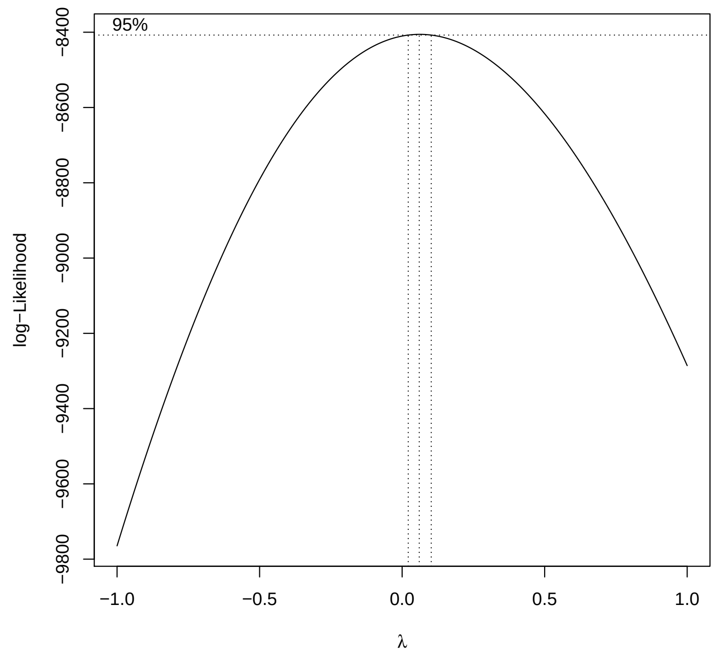
Table A.11: Heidelberger-Welch MCMC Diagnostics

	Stationarity Test p-value	Mean	Halfwidth	Ratio
Interpect	0.176	-87.156	2.461	-0.028
Senior	0.644	0.049	0.000	0.010
Groundwater	0.972	0.134	0.001	0.005
Residential	0.516	0.190	0.000	0.002
Reservation	0.268	-0.139	0.001	-0.007
Benton	0.915	0.232	0.001	0.003
Kittitas	0.702	0.653	0.001	0.002
Acres	0.088	-0.010	0.000	-0.001
Acres^2	0.053	0.000	0.000	0.002
Improvements	0.482	0.000	0.000	0.002
Rolling Avg TWSA	0.101	0.052	0.000	0.009
Deviation TWSA	0.657	-0.037	0.000	-0.007
Time	0.219	0.002	0.000	0.020
Time^2	0.234	0.000	0.000	0.021
Time^3	0.291	-0.000	0.000	-0.023
Rolling Avg	0.189	27.512	0.864	0.031
Rolling Avg^2	0.199	-2.777	0.101	-0.036
Rolling Avg^3	0.209	0.092	0.004	0.043
Soil Productivity	0.259	0.207	0.001	0.004
Soil Productivity^2	0.236	-0.003	0.000	-0.004
Soil Productivity^3	0.219	0.000	0.000	0.004
Slope	0.329	0.012	0.000	0.010
Slope^2	0.111	-0.002	0.000	-0.004
Slope^3	0.090	0.000	0.000	0.004
Dist Stream	0.207	-0.133	0.001	-0.006
Dist Stream^2	0.508	0.100	0.000	0.003
Dist Stream^3	0.525	-0.013	0.000	-0.003
Dist City	0.598	0.010	0.000	0.003
Residential - ID 20NN	0.849	-0.231	0.003	-0.011
Improvements - ID 20NN	0.213	0.000	0.000	0.004
Slope - ID 20NN	0.917	0.040	0.000	0.002
Orchard_1	0.155	0.221	0.000	0.002
Developed_1	0.632	0.191	0.001	0.003
σ^2	0.354	0.480	0.000	0.000

Table A.12: Autocorrelation of MCMC draws

	Lag 0	Lag 1	Lag 5	Lag 10	Lag 50
Interpect	1	-0.004	0.010	0.005	0.012
Senior	1	-0.010	0.003	-0.004	-0.004
Groundwater	1	0.009	0.001	0.003	-0.005
Residential	1	-0.004	0.011	-0.007	-0.007
Reservation	1	0.002	0.003	0.007	0.000
Benton	1	0.002	-0.004	0.000	0.005
Kittitas	1	0.001	-0.008	0.004	0.007
Acres	1	0.002	0.000	-0.002	0.006
Acres^2	1	0.005	-0.002	0.000	0.005
Acres^3	1	0.006	-0.001	0.002	0.007
Improvements	1	-0.004	0.001	0.008	-0.005
Improvements^2	1	-0.003	-0.000	0.007	-0.002
Rolling Avg TWSA	1	-0.000	0.000	0.000	0.007
Deviation TWSA	1	0.004	-0.003	-0.000	0.001
Time	1	-0.004	-0.005	0.008	0.006
Time^2	1	-0.003	-0.003	0.008	0.006
Time^3	1	-0.003	-0.002	0.008	0.006
Rolling Avg	1	-0.004	0.010	0.005	0.012
Rolling Avg^2	1	-0.004	0.010	0.005	0.012
Rolling Avg^3	1	-0.004	0.010	0.005	0.012
Soil Productivity	1	0.003	0.004	0.001	0.002
Soil Productivity^2	1	0.002	0.005	0.002	0.002
Soil Productivity^3	1	0.002	0.005	0.002	0.002
Slope	1	0.004	0.000	-0.010	-0.012
Slope^2	1	0.008	-0.005	-0.008	-0.009
Slope^3	1	0.010	-0.006	-0.004	-0.007
Dist Stream	1	0.007	-0.006	-0.001	0.005
Dist Stream^2	1	0.010	-0.002	-0.001	0.006
Dist Stream^3	1	0.011	-0.001	-0.004	0.006
Dist City	1	-0.001	0.005	0.006	-0.004
Residential - ID 20NN	1	0.007	-0.007	0.004	0.010
Improvements - ID 20NN	1	0.002	0.002	-0.003	0.002
Slope - ID 20NN	1	0.009	0.005	0.006	-0.004
Orchard$_1$	1	-0.002	-0.007	0.001	-0.005
Developed$_1$	1	0.003	-0.001	0.007	-0.008
σ^2	1	0.010	-0.004	-0.004	-0.012

Figures



Note: This is the a Box-Cox test for model specification in the base regression. Values of λ range from -1 to 1 in increments of 0.01. The preferred value of λ is 0.06, and the 95% confidence interval barely excludes zero.

Figure A.1: Box Cost Test