The Value of Heterogeneous Property Rights: The Costs of Water Volatility

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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 secure water rights through their capitalization in agricultural property markets using spatially explicit water rights data in the Yakima River Basin, a major watershed in Washington State. The Yakima River watershed, like many Western watersheds, satisfies all water claims during an average year so the benefits of secure water rights stem from protection against water curtailment during drought years. Thus the relative value of secure property rights is a function of water supply volatility because the costs of droughts are predominantly born by those with weak rights. In a hedonic price model I find that farmers pay a premium of 9-12% for more secure water rights. I use Bayesian model averaging to deal with model uncertainty and the potential omitted variable bias prevalent in hedonic analysis. An endogenous change point model tests whether the premium on a senior right varies over time, potentially in response to expectations about climate change. The results fail to confirm that farmers' expectations about future water supply volatility are manifested in agricultural water markets.

1. Introduction

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 complexity in the prior appropriation doctrine leads to costly adjudication to resolve conflicts regarding both the quantity and priority of water rights[1]. The obfuscation of property rights generates transaction costs impeding the efficient reallocation of water through markets to address threats of water scarcity associated with climate change (Libecap 2011). Climate models predict that regions around the world will face more variable water supplies; due to changes in precipitation patterns and higher temperatures resulting in less water stored as snowpack. In particular, the Western United States is expected to experience more frequent and severe droughts in the summer – the season of peak water demand (Bates et al. 2008). Quantifying the heterogeneity in water rights is crucial for determining the distributional impact from climate change, as owners of low-priority rights will bear most of the costs of volatile water supplies. The value of priority in water rights, referred to as seniority, is difficult to directly estimate through water right transactions due the thinness of water markets. The goal of this paper is to first estimate the value of security in agricultural water rights, and second, to test if the premium paid for more secure rights increases over time in response to expectations about water volatility associated with climate change.

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.

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

High priority[2] (also referred to as senior or non-proratable) rights were established before 1905 while all subsequently established rights are designated as junior (or proratable) and are subject to curtailment when water supply falls short of total entitlements. There has never been an incidence of curtailment of senior rights; thus priority effectively insulates farmers from temporal shocks to the water supply. 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 where the region experiences water shortages. Water shortages that have historically occurred in 14% of years will 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 snowpack 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 first I employ the hedonic price model to estimate the premium associated with a senior water right. Next I test if the premium changes over time in accordance with farmers' belief about increasing water variability, potentially due to climate change. Initial results indicate that the additional security associated with a senior water right adds 9-12% of the value of a farm. There is no a priori designation for when climate change begins to impact landowners' expectations so I use a model with an

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[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.

endogenous change point to test for a time varying premium on senior water rights. Results show that the change point is at the end of the sample – evidence that there really may not be a change point at all. While this approach imposes parametric restrictions on the form of the time-varying parameter it provides a starting point to test for behavioral response to climate change in the property market. Incorporating survey or polling data provides a more flexible definition of climate change and is left for further research. While this study focuses on the impacts in the Yakima River Basin of central Washington, the phenomenon of increasing volatility of water supply applies to many regions facing a changing climate, particularly those that rely on snowpack as a source of water supply in the summer. The rest of the paper is organized as follows. Section 2 presents a background of the literature and the study area, Section 3 introduces the economic model, Section 4 describes the data, estimation methodology empirical results, and a policy application, and Section 5 concludes.

2. Background

2.1 Related Literature

The contribution of this paper is to value heterogeneous water rights and relate the relative value of secure rights to water volatility. The first application of the hedonic price model value to water rights was Crouter (1987), who tests 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 & Perry 1999) and the ecological value of in-stream flow (Netusil & Summers 2009). However, there are no studies that estimate the impact of variations in the right itself. Other research analyzing property rights with varying degrees of security focuses on 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 & Graham-Tomasi (1991) builds on the research of optimal groundwater extraction (Burt 1964). Tsur et al. (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; but are biased if farmers change crops, irrigation and fertilization technologies, or land use (Mendelsohn, Nordhaus, and Shaw 1994). Alternatively, using property values to estimate the effect of water supply volatility incorporates the potential of landowner adaptation 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 see (Schlenker, Hanemann, and Fisher 2005) and (Deschenes and Greenstone 2007) among others. Mendelsohn & 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 farm values. While these articles rely on county level data, Schlenker, Hanemann, & Fisher (2007) use farm-level data in California to show that water availability strongly capitalizes into farm prices.

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 precipitation, average temperature, 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. Conversely, hedonic models explicitly value irrigation water or groundwater with micro-level data on water rights or permits for digging wells (Butsic and Netusil 2007; Crouter 1987; Faux and Perry 1999; Netusil and Summers 2009; Petrie and Taylor 2007). There is evidence that pooling irrigated and non-irrigated land is not appropriate in identifying the effect of climate on farmland values since precipitation and temperature have very different impacts when land is augmented by irrigation (A. Fisher et al. 2012; W. Schlenker et al. 2005). 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.

2.2.1 Agriculture in the Yakima River Basin

The Yakima River Basin in Central Washington State provides an excellent test case to examine the interaction of priority in water rights and water supply volatility because landowners with junior rights bear the preponderance of the costs due to drought. The Yakima River Basin is one of Washington's largest agricultural producer, contributing close to 20% of the state's $9.2 billion worth of agricultural output in 2011[3]. Much 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 (2011)[4] estimates over $130 million in economic losses from decreased agricultural production from the 2001 drought alone. 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. Increased frequency of severe drought years will diminish the relative value of farmland with junior water rights. Rational landowners will react to threats to water volatility, and this research tests whether they consider climate change as a real threat to their water supply. The next sections describe the features of the Yakima basin, and motivate the use of water rights to test for expectations of water supply volatility.

2.2.2 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 regions falls between October and March (USBR, 2002

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

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

and WRCC, 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 met predominantly by surface water. Five major reservoirs operated by the U.S. Bureau of Reclamation (USBR) with a combined total 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. This fraction increases when non-federally supplied irrigation districts are included, justifying the use of irrigation districts to analyze the impact on the region's agricultural sector.

The USBR operates reservoirs with the joint goals of flood control and the provision of irrigation water from April through September. Melting snowpack 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 snowmelt, preventing the use of snowmelt during the irrigation season and reducing its substitutability with reservoir water. Therefore the quantity and timing of snowpack is crucial to the water supply system in the Yakima.

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 around 1970 but since the 1990s the basin experiences violent dips in water use due to severe droughts that are particularly acute for the 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.

Insert Figure 1 here

2.2.3 Water Rights in the Yakima Basin

The institutions governing water rights in Yakima River basin simplifies estimating 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, or non-proratable, rights and all rights post-1905 are designated as junior rights, or 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. For example, consider 50 landowners with junior rights and 50 with senior rights where everyone 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. 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 right holders have never been affected by prorating. Therefore junior water rights holders are more susceptible to seasonal and annual variation and will bear the majority of the costs due to 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 all senior rights and some districts have a mix of both non-proratable and proratable rights. I distinguish the districts with both types of rights based on the two reports from the USBR (U.S. Bureau of Reclemation 2011; USBR 2011b) that indicate Roza, KRD, and WIP 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 cutoff for a district that is defined as senior. This cutoff conforms with the literature (Vano et al. 2010) that prorating is particularly damaging below 70% and the fact that junior districts experience withdrawal reductions more than 30% below their historical average in Figure 1. Table 1 shows the properties in our sample by irrigation district with the percentage of non-proratable rights and a junior or senior designation for the district. The sample matches up closely with the population of water rights with 52% of properties having predominately junior rights.

In theory an active water market will alleviate some of the costs of water shortages by distributing water from low-value uses to activities with higher marginal value. While substantial gains to trade exist in years where junior water users suffer from severe prorating, water transactions developed slowly and there is still not a well-functioning water market in the region. Beginning in 2001 the Yakima basin initiated a water trading program during emergency drought conditions, as declared by the state. However, two complications prevent the operation of a competitive water market in the region. First, the necessary infrastructure to transfer water between all interested agents does not exist and second, legal obfuscations generate disinclinations to engage in trade. Water rights in Washington require the user to establish beneficial use, and if water remains idle for five consecutive years an owner relinquishes their right. Farmers are often hesitant to sell water because they need to prove they put the water to beneficial use if required to defend their right in court. Another concern is that the examination of the water right during the transaction may reveal that the right is not valid, or represents a smaller quantity of water than actively used by the farmer.

Insert Table 1 here

2.2.4 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). So even though all prorating has costs, the most severe burden occurs in years where junior farmers receive less than 70% of their water right. According to downscaled climate models by Vano et al. (2010) precipitation will increase in the cool months and decrease during irrigation season. Rising temperatures will decrease the snowpack 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, 2011a). In summary, climate changes will exert pressure on water supply and demand through reduced precipitation during the irrigation season, earlier snowpack, and higher temperatures. Furthermore, rising water supply volatility will increase the years where prorating goes 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. Economic Model

I use the hedonic price model to estimate the implicit value of a senior water right in the Yakima basin. Rosen (1974) develops the hedonic price model in application to the residential housing market, and Palmquist, (1988), (1989) extends 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

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

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

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

By differentiating *(3)* it can be shown that $\frac{\partial \theta_t}{\partial X_i} = \frac{\partial \pi^{*V}}{\partial X_i}$ and $\frac{\partial \theta_t}{\partial W} = \frac{\partial \pi^{*V}}{\partial W}$. 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 $\boldsymbol{X}$, 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.

$$q_t(\mathbf{p_t}, \mathbf{X}, W_t, \alpha) = \sum_{t=0}^{\infty} E_t[\pi_t^{*V}(\mathbf{p_t}, \mathbf{X}, W_t, \alpha)]e^{-\beta t} \tag{4}$$

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 $\overline{\pi}_t$ is the expectation of future net profits.

$$\Theta_t(\mathbf{p_t}, \mathbf{X}, \pi_t, W_t, \alpha) = \sum_{t=0}^{\infty} E_t[\pi_t^{*V}(\mathbf{p_t}, \mathbf{X}, W_t, \alpha)]e^{-\beta t} - \overline{\pi}_t \tag{5}$$

In this forward looking model $\frac{\partial \Theta_t}{\partial W_t} = \frac{\partial \sum_{t=0}^{\infty} E_t[\pi_t^{*V}]e^{-\beta t}}{\partial W_t}$; the marginal increase in the bid on 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[5], 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). Where the distribution of water $W \sim g(\mu, \sigma^2)$ can be described by its mean and variance[6], and $\widetilde{\pi}()$ is the profit function optimized with respect to all other inputs conditional on W.

$$\gamma = \sum_{t=0}^{\infty} \widetilde{\pi_t^{*V}}(\mu) e^{-\beta t} - \sum_{t=0}^{\infty} E_t \left[\widetilde{\pi_t^{*V}}(W_t)\right] e^{-\beta t} \tag{6}$$

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 landowner's expected profit, $E\left[\widetilde{\pi_t^{*V}}(W_t)\right]$, 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[7]. Whether (7) holds in practice likely depends on the setting, particularly the domain of $\widetilde{\pi}$. In this setting it appears feasible due the public discourse on the costs of water scarcity. The analysis does not rely on this assumption, but rather is testing it directly by estimating γ as an attribute in the hedonic price with

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

[6] 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.

[7] 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.

only the traditional assumptions in the hedonic model. The key point is that if $\gamma > 0$ then $\frac{\partial \gamma}{\partial \sigma^2} > 0$ likely; and estimating a time-varying premium is an indication of changing expectations of water supply volatility.

4. Empirical Application

4.1 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 sales, 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; dropping sales of parcels outside of irrigation districts. Using sales from 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; obfuscating 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 data water rights, 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 use sales from 1990-2011 to increase the likelihood of capturing changing expectations of water supply volatility. However, the long time horizon also poses challenges due to changing market conditions over time. I spatially match soil characteristics from the Unites States Department of Agriculture (USDA) SOILMART 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, as well as spatial data of supplemental water rights are obtained from the Washington State Department of Ecology (ECY) and generated through GIS. The additional water rights are spread evenly across all irrigation districts and between those that have junior and senior rights. These supplemental rights provide water to livestock and people on the farm, and may be used to supplement water from the irrigation district, but are generally not enough to sustain agriculture. Table 2 displays summary statistics for continuous variables and sample percentages for binary variable.

Insert Table 2 here

4.2 Econometric Model

I employ a Bayesian linear regression model with normal independent Gamma priors and a general covariance matrix as employed by Koop (2003). The regression function is $y = X\beta + \epsilon$, where y is the real log sale price per acre, X is a matrix of covariates, β is a coefficient vector and ϵ is a heteroskedastic error term distributed $\epsilon \sim N(0, \sigma^2\Omega)$. A Box Cox test provides strong evidence for a log-linear model[8]. The notation for any parameter θ follows Koop (2003) where $\underline{\theta}$ represents the prior value that is chosen by the analyst and $\overline{\theta}$ 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

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[8] 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.

information on the parameters – the full description of the likelihood, priors, and joint posterior is available in the Appendix.

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 distribution, and Ω is estimated in the third block, with the distribution depending on the assumptions of the error term. The conditional posterior distributions for β and σ^2 are given by

$$p(\beta|y,\sigma^2,\Omega) \sim N(\bar{\beta},\bar{V}) \tag{8.1}$$

$$p(\sigma^2|y,\beta,\Omega) \sim I\Gamma\left(\frac{\bar{\nu}}{2},\frac{\bar{\nu}\bar{s}^2}{2}\right) \tag{8.2}$$

where $\bar{V} = \left(\underline{V}^{-1} + \sigma^{-2}X'\Omega^{-1}X\right)^{-1}$, $\bar{\beta} = \bar{V}\left(\underline{V}^{-1}\underline{\beta} + \sigma^{-2}X'\Omega^{-1}X\hat{\beta}(\Omega)\right)$, $\bar{\nu} = n + \underline{\nu}$, and $\bar{s}^2 = \frac{((y-X\beta)'\Omega^{-1}(y-X\beta)+\underline{\nu s^2})}{\bar{\nu}}$. I do not impose direct structure on the form of heteroskedasticity, but make parametric assumptions to aid in the computation. Specifically, I assume that Ω is a diagonal matrix with the precision distributed independent gamma. The intuition is that all error variances may be different, but they are drawn from the same distribution. The mean of the distribution is assumed to be zero, a trivial assumption, and the variance of the distribution is estimated within the model. This leads to two more parameters to estimate as additional blocks in the Gibbs sampler.

$$p(\lambda_i|y,\beta,\sigma^2,\nu_\lambda) = \Gamma\left(\frac{\nu_\lambda+1}{2},\frac{2}{h\epsilon_i+\nu_\lambda}\right) \tag{8.3}$$

$$p(\nu_\lambda|y,\beta,\sigma^2,\lambda) \propto \left(\frac{\nu_\lambda}{2}\right)^{\frac{n\nu_\lambda}{2}} \Gamma\left(\frac{\nu_\lambda}{2}\right)^{-n} \exp(-\eta\nu_\lambda) \tag{8.4}$$

where $\eta = \frac{1}{\underline{\nu_\lambda}} + \frac{1}{2}\sum_{i=1}^{n}[\ln(\lambda_i^{-1}) + \lambda_i]$.

The structure of the priors for Ω, shown in the Appendix, leads to the errors being distributed as a student-t with mean zero, variance σ^2 and degree of freedom ν_λ. The degree of heterogeneity depends on ν_λ, the scale parameter in the distribution of λ, and is explicitly estimated within the model. Since the posterior for ν_λ is not of a standard form I use the Metropolis-Hastings algorithm to draw from a candidate generating function and then use an acceptance criteria to accept or reject a given draw. Figure A1 in the Appendix shows the histogram for the posterior estimates of ν_λ and the Metropolis-Hastings acceptance rate. The final model has four blocks in the Gibbs sampler that draws from the joint posterior of $p(\beta,\sigma^2,\lambda,\nu_\lambda|y)$.

I employ Bayesian estimation techniques for two reasons. The first is the ease of adding additional elements to the model in the form of new Gibbs blocks, and the second is to alleviate omitted variable bias 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. The posterior model probability for model *i* as shown in Koop (2003) is

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

where $\boldsymbol{y}$ 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 25 candidate regressors lead to over 33 million potential models and makes estimating and evaluating each unique model intractable. One form of BMA developed by Raftery, Madigan, and Hoeting (1997) takes advantage of Markov Chain Monte Carlo Model Composition (MC^3) that precludes estimating each separate model and converges to the region with the highest model posterior probabilities. The MC^3 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 $p(\text{accept new model}) = \min\left[1, \frac{p(M_j|y)}{p(M_i|y)}\right]$.

4.3.1 Results

Table 3 presents the results from the BMA model. The coefficients are weighted by the posterior probabilities, and assigned a value of zero for models in which they do not appear. The last column displays the count of how many times a variable is selected in models that account for at least 1% of total posterior weight (a total of 15 models met this criterion). While the results from the BMA can be interpreted directly it is also useful to select a baseline model to see how it changes under certain scenarios that have economic implications. Additionally, BMA is computationally intensive and becomes intractable for more complicated models such as adding a Gibbs bloc for an endogenous changepoint. To be conservative when selecting a base model I include all variables that show up at least once in any model comprising at least 1% of the posterior mass in the

BMA. I also include an amelioration set of variables suggested by the prior literature. We can compare variants of the base model to the base model itself and the BMA results. Since the Gibbs sampler uses a Markov Chain process to draw from the joint posterior distribution it is important to ensure that the effect of the initial values has disappeared. I perform several MCMC diagnostics to test whether the Gibbs sampler has converged to the true joint posterior. First, as seen in Table A1 in the Appendix looking at the autocorrelation in the draws suggests that by 5 lags the autocorrelation has mostly disappeared. Additionally, I perform the Geweke (Geweke 1992) chi-square test for the equality of means in two separate intervals of the Gibbs draws. For all parameters the p-values are greater than 10% failing to reject the hypothesis of different means as displayed in Table A2 in the Appendix.

Insert Table 3 here

The posterior distribution on the senior right variable reveals 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. Table 4 shows the estimates for the base model and Figure 2 displays the posterior distribution for the senior water right with the dashed lines designating the 95% highest posterior density interval – the Bayesian analog to 95% confidence intervals. Variables that appear consistently in all top 15 BMA models have similar coefficients while those that do not appear as often are drawn to zero in the BMA model.

Insert Figure 2 here

Insert Table 4 here

In both the BMA model and the base model the mean of the posterior distribution for the senior water right coefficient is positive and significant from zero at the 1% significant level. The BMA model predicts a 9.5% increase in the price per acre of farmland, corresponding to \$706 evaluated at the mean farmland value[9] whereas the base model predicts values of 12.2% and \$861 respectively. The annualized value per acre-foot of water is approximately \$10.09 in BMA and \$13.08 and the base model, which fits in the context of Faux & Perry (1999) that finds that an acre-foot of irrigation water ranges from \$9-44. A key distinction is that in this study I find that \$10.09-13.08 is the range of values for *more secure* irrigation water suggesting it is critical to account for heterogeneity in water rights. Additionally, the notion that irrigated and non-irrigated land may respond differently to climate change is noted in Schlenker et al. (2005), and makes this study attractive by having a sample comprised exclusively of irrigated land.

The other parameters have intuitive results. The real per-acre value of land in the Yakima basin is increasing over time, where time is defined as quarters from the first observed sale. The dummy for residential structures is positive and significant as is the coefficient for market improvements on the land. I add the percentage of land in each soil class based on the suggestion of Faux & Perry (1999) even though they do not show up in the top BMA models. As expected based on the BMA results, the means of these variables' posterior distributions are not significantly different from zero.

4.3.2 Robustness

An interesting result is the significance and magnitude of the mean of the distribution for supplemental water rights – in the base model the mean value of a

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[9] The interpretation of the marginal effect of the coefficient on the dummy for senior water rights on the per-acre sale price equals $100[\exp(\beta_D - 1)]$ as shown by Halvorsen & Palmquist (1980).

supplemental right at 15.6% is higher than the premium for senior rights. As explained earlier these rights are mostly likely not the primary source of irrigation but offer some extra water in the form of a stream, groundwater wells, or additional Yakima River surface water rights. According to the theory the value of a senior right stems from insulating the landowner from water supply shocks so the benefits of supplemental rights should be greater for those with junior primary rights. Figure 3 shows the posterior distributions for the coefficient on supplemental water rights for the sample divided by the priority of primary rights. The mean of the posteriors suggest that supplemental rights add 0.8% and 25.5% to the farm values for senior and junior rights respectively; however there is significant shared probability mass between the two distributions. The finding that supplemental water predominantly benefits those with junior primary rights supports the initial claim that water rights are heterogeneous and priority insulates landowners from the effects of drought. It is important to consider the economic significance of these results. There is a relatively equal proportion of land with junior versus senior rights in the basin; and water supplied through irrigation districts is the primary source of irrigation water. Meanwhile, only 8.5% of properties have supplemental rights[10]. The low prevalence of supplemental rights along with the rarity of successful new water right applications in the regions suggest that supplemental rights play a limited role in dealing with water scarcity in the region.

I also run regressions for separate counties in the sample and Table 5 displays the posterior means along with the 95% highest posterior density intervals. One element that stands out is that the posterior for senior rights has a mean close to zero for Benton

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[10] The proportion of supplemental rights on land with junior primary rights is 56%, slightly higher than the 52% of properties with junior primary rights in the sample.

County. Recall that the biggest irrigation district in Benton County with predominantly junior rights, Kennewick Irrigation District, has a more stable water supply than other junior districts due to recharge from upstream users. So the county regressions further support the hypothesis that the value of a senior water right is connected to the water supply volatility.

Insert Figure 3 here

Insert Table 5 here

4.3.3 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 in calculating 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. I calculate the gains to agricultural production by multiplying 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. I believe this approach is justified since these districts represent a significant proportion of total agricultural land and the estimates can be directly compared to the results in the Integrated Plan. Using the hedonic approach the benefits from more secure water rights range between \$136 and \$234 million depending on the using the BMA or base results and whether Kennewick

Irrigation District is included. These results are significantly 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. This fits into the general discourse that economic research does not fully permeate through to water policy. Research suggests the relative benefits of more fluid water markets compared to large government funded infrastructure projects, but unfortunately policy has not caught up with the economics (Olmstead, 2010). These calculations rest on the assumption that the premium for land in senior districts is constant throughout the sample period. This assumption is not valid if climate change alters landowners' expectations about future water supply volatility which we address in the next below.

4.3.4 Non-Stationary Costs of Water Volatility

Establishing a climate change scenario is the first step in testing 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. I pool the data into two periods: pre-2005 and post-2005 and run regressions, and then repeat the process for pre and post-2001. Figure 4 shows the posterior distributions for the senior water right coefficient when pooling the data before and after the two most recent major droughts. Using either drought to partition the data indicates that the premium on a senior right may not be stationary as the central tendency of the distributions shifts to the right in more recent years. However, there is a significant shared probability mass between the two distributions suggesting that an ad hoc approach to testing for climate change is not sufficient.

Insert Figure 4 here

Since there is no established climate change treatment period I look to the data to find evidence for dividing of the sample. This is akin to testing for parameter instability on the coefficient on a senior water right, and follows the logic of models with a changepoint commonly used with time series data. I augment the normal independent Gamma model by adding an additional Gibbs block to estimate the full distribution for a changepoint parameter. The methodology is used to test for a structural break in the time trend of U.S. temperature (Li and Tobias 2011). First I order the data by sale date - it should be noted that this is cross sectional data so there are multiple observations per time period. The augmented model partitions the data dependent on θ. For our purposes $X_{2(\theta)}$ will contain all the same covariates as $X_{1(\theta)}$ as well as an interaction term of the senior dummy with a time trend, allowing for parameter instability in the coefficient on a senior water right.

$$y_{it}|\beta,\tilde{\beta},\sigma^2,\lambda,\nu_\lambda,X_{1(\theta)},X_{2(\theta)}\sim\begin{cases}N(x_{it}\beta,\sigma_i^2)\ if\ t\leq\theta\\N(x_{it}\beta,\sigma_i^2)\ if\ t>\theta\end{cases}$$

$X_{j(\theta)}$ for *j* = 1,2 denotes the full set of regressors under each regime, where

$$X_{1(\theta)}=\begin{bmatrix}X_{1,1}\\X_{2,2}\\\vdots\\X_{i,\theta}\end{bmatrix}\ and\ X_{2(\theta)}=\begin{bmatrix}X_{i+1,\theta+1}\\X_{i+2,\theta+2}\\\vdots\\X_{n,T}\end{bmatrix}$$

I use an uninformative uniform prior for θ, and since the θ is discrete-valued I can calculate the unnormalized ordinates for $\theta\in\{1,\ldots,T\}$. Normalizing the ordinates by dividing each ordinate by the sum of all unnormalized ordinates produces a discrete valued distribution from which I can draw values of θ. The prior for θ is simply $\frac{1}{T}$, all other parameters are as defined in the base model, and the posterior is given by

$$p(\theta|y) \propto p(\theta)|D_\theta|^{-\frac{1}{2}}\left[\frac{\underline{\nu}\underline{s}^2}{2}+\frac{1}{2}\left(y-X_{(\theta)}\underline{\beta}\right)' D_{(\theta)}^{-1}\left(y-X_{(\theta)}\underline{\beta}\right)\right]^{-\frac{n+\underline{\nu}}{2}} \tag{10}$$

where $D_{(\theta)} \equiv I_n + X_{(\theta)}\underline{V}X'_{(\theta)}$.

I select quarters as the unit of time because the posterior is discrete and there are not many years, while using months requires significantly more computation time. The results are robust to different units of time at low levels of draws for the Gibbs sampler. The median of the change point parameter is 83 corresponding to a change point in the third quarter of 2010. This is very close to the end of the sample suggesting there the coefficient on the senior water is stable over time. Figure 5 shows graph of the full set of frequencies of posterior estimates for θ.

Using a linear interaction after a certain time may be an overly simplistic methodology to identify a climate change scenario; however it appears to be an appropriate starting point. There are many factors that contribute to belief in climate change. Creating a continuous or discrete index of climate variables may be more appropriate than a monotonic linear approach. This will allow farmers to expectations of climate change to ebb and flow as the conditions change. Discussions with employees at the USBR and irrigation districts suggest that farmers are aware of snowpack and TWSA estimates. Regressions run with lagged proration rates and TWSA estimates interacted with senior dummy do not produce significant results. Another approach is to employ continuous measures of climate perceptions such as surveys or opinion polls, and is left for future research.

5. Conclusion

Increasingly frequent demand and supply shocks from 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 paper quantifies the value of priority for senior water rights as a mechanism to protect landowners against the effects of droughts. The central tendency of the posterior distribution for senior water rights is significant under all specifications, and comprises 9-12% of the per-acre value for the average farm in the Yakima Basin. Using the estimates from the posterior distribution of the senior water right coefficient in a benefit cost framework suggests that the methodology employed by the Integrated Plan overestimates the agricultural benefits associated with enhanced storage capacity in the basin. This finding depends on the assumption that the full sample of housing sales is representative of farmer's expectations of climate change induced water scarcity. If farmers' expectations changed since 1990, the coefficient on senior water rights will also change. More specifically, if farmers respond to climate change by increasing the demand for water security, the premium paid for land in districts with senior rights will increase. Pooling the samples based on recent severe droughts suggests higher premiums for priority after the droughts. However, explicitly estimating an endogenous changepoint does not support the hypothesis of a time-varying premium. This research finds that while farmers in central Washington do pay for security in agricultural water rights, expectations about changing water supply volatility are not manifested in property markets. Further research can pursue the link between water volatility and the price of water security by exploiting cross sectional variation in water supply volatility. As is often the case with studying water rights gathering high quality data and finding regions with comparable institutions remains a challenge.

Appendix:

A1. Bayesian Model Specification

The basic structure of the linear regression with a general covariance matrix is taken from Koop (2003). The regression function is $y = X\beta + \epsilon$, where y is the real log sale price per acre, X is a matrix of covariates, β is a coefficient vector and ϵ is a heteroskedastic error term distributed $\epsilon \sim N(0, \sigma^2\Omega)$. I first outline the model with general covariance matrix $\sigma^2\Omega$, and the restrictions I impose to aid estimation. The likelihood function is

$$p(y|\beta, \sigma^2, \Omega) = (2\pi\sigma^2)^{-\frac{n}{2}}|\Omega|^{-\frac{1}{2}}\left[\exp\left(-\frac{1}{\sigma^2}(y - X\beta)'\Omega^{-\frac{1}{2}}(y - X\beta)\right)\right] \tag{A11}$$

and the priors are

$$p(\beta) \sim N\left(\underline{\beta}, \underline{V}\right) \tag{A12.1}$$

$$p(\sigma^2) \sim I\Gamma\left(\frac{\underline{\nu}}{2}, \frac{\underline{\underline{\nu s^2}}}{2}\right) \tag{A2.2}$$

$$p(\Omega) \sim p(\Omega) \tag{A2.3}$$

Prior values are $\underline{\beta} = 0$, $\underline{V} = 1000^2 * I_k$, $\underline{\nu} = 1$, and $\underline{s^2} = 1^{-10000000}$. This leads to a joint posterior of the following form

$$p(\beta, \sigma^2, \Omega|y) \propto p(\Omega)\left[\exp\left(-\frac{1}{2}\begin{bmatrix}\frac{1}{\sigma^2}(y - X\beta)'\Omega^{-1}(y - X\beta) + \\ \left(\beta - \underline{\beta}\right)'\underline{V}^{-1}\left(\beta - \underline{\beta}\right)\end{bmatrix}\right)\right]\left(\frac{1}{\sigma^{n+\nu-2}}\right)\exp\left(\frac{\underline{\nu}}{2\sigma^2\underline{s}^{-2}}\right). \tag{A13}$$

Since this posterior is not of standard form we draw from the conditional posterior distributions for β, σ^2, given in equation (8).

I will not assume that I know the structure of the heteroskedasticity, but will make some parametric assumptions to aid in the computation The structure of Ω is given by with the following priors

$$\Omega = \begin{bmatrix} \omega_1 & 0 & \dots & 0 \\ 0 & \omega_2 & 0 & \vdots \\ \vdots & 0 & \ddots & 0 \\ 0 & \dots & 0 & \omega_n \end{bmatrix} \mathit{and}\ \lambda \equiv (\lambda_1, \lambda_2, \dots, \lambda_n)' \equiv (\omega_1^{-1}, \omega_2^{-1}, \dots, \omega_n^{-1})'$$

$$p(\lambda) = \prod_{1=1}^{n} \Gamma\left(\frac{\nu_\lambda}{2}, \frac{2}{\nu_\lambda}\right) \tag{A14.1}$$

$$p(\nu_\lambda) \sim \Gamma\left(1, \underline{\nu_\lambda}\right) \tag{A4.2}$$

We use a value of $\underline{\nu_\lambda} = 15$, and the conditional posterior for λ_i and ν_λ are given in equation (8). Figure A1 shows a histogram for the posterior estimates of ν_λ in the top panel and the M-H acceptance rate in the bottom panel.

Insert Figure A1 here

A2. MCMC Convergence Diagnostics

The Gibbs sampler is an MCMC procedure where arbitrary initial values may bias the results. There are several diagnostic tools used assess if the Gibbs sampler converged to the true joint posterior distribution and the effect of the starting values has worn off. We employ three tools that all indicate that the Gibbs sampler in reached convergence. The I-stat 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. and was developed Raftery & Lewis (1992). For accuracy level of 1% the I-stat is 1.047, safely below the recommended threshold of 5. Next we present the serial correlation for all the parameters. The low level of serial correlation in the Gibbs draws as shown in Table A1 provides evidence that the draws represent and independent sample. Lastly we show the results for

Geweke χ^2 test for equality in means for two regions of the Gibbs sampler – we use the first 20% and the last 50% of the Gibbs 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 A2 shows the p-values for χ^2 test of the null that the means are equal. In all cases the test fails to accept the null at the 90% level. These diagnostics tool suggest that the Gibbs sampler has reached convergence; and this is not a surprise given that running 220,000 draws with 20,000 burn-in draws is circumspect.

Insert Table A1 here

Insert Table A2 here

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Tables

Table 1: Water Rights and Irrigation Districts

Name	# of Sales	% of Senior Rights	Senior Designation
Ahtanum	23	100	Yes
Buena	6	100	Yes
Cascade	39	100	Yes
Columbia	30	100	Yes
Ellensburg Water	35	100	Yes
Kittitas Reclamation	186	6.9	No
Kennewick	201	7.8	No
Moxee-Selah	16	85.6	Yes
Naches-Selah	32	91.1	Yes
Roza	471	0	No
Sunnyside Valley	0	72.5	Yes
Union Gap	0	79.1	Yes
Wenas	14	0	No
West Side	0	75.8	Yes
Yakima-Tieton	0	65	Yes
Yakima-Wapato	268	48.7	No
Total	2,166	-	1,026

Note: The table shows observations from each district by row and the type of water rights in the columns. The sample has a slightly higher proportion (52%) of senior water rights than the population (55%) in the basin.

Table 2: Summary Statistics

Variable	Unit	Mean	Std.Dev.	Min	Max
Price-per-acre	2008 USD	7,054	5,971	516.6	29,647
Sr	Binary	0.474	0.499	0	1
Residential	Binary	0.295	0.456	0	1
Groundwater Right	Binary	0.0854	0.280	0	1
Rolling Avg	2008 USD	6,331	2,047	1,948	13,390
Acres	Acres	41.80	51.73	1	680.4
Class 1	%	0.381	0.383	0	1
Class 2	%	0.275	0.326	0	1
Class 3	%	0.186	0.283	0	1
Class 4	%	0.000502	0.0208	0	0.965
Class 5	%	0.156	0.276	0	1
Improvements-per-acre	2008 USD	3,593	4,903	0	29,756
Distance to City	Miles	36.53	21.67	2.884	92.36
Distance to Stream	Miles	1.981	1.613	0	8.123
Inverse Distance to Urban Growth Area	1/Miles	54.19	316.5	0.0578	2029
Inverse Distance to Yakima River	1/Miles	0.881	5.691	0.0424	204.0
Kittitas	Binary	0.125	0.330	0	1
Benton	Binary	0.327	0.469	0	1

Note: Similar to Faux & Perry (1999) observation are eliminated if they are less than 1 acre and greater than $30,000 per acre. Class variables represent the percentage of each parcel that falls within that class. Slope is the average slope of the entire parcel. For binary variables the mean represents the proportion of observations for which the binary variable is equal to 1.

Table 3: Bayesian Model Averaging

Variable	Posterior Mean	t-statistic	t-probability	Count in top 15 models
Constant	7.166056	79.159821	0	NA
Sr	0.095496	2.81305	0.004951	NA
Time	0.013288	11.741287	0	15
Time^2	-0.000019	-0.586345	0.557705	4
Acres	-0.002493	-7.632254	0	15
Improve	0.000041	11.905792	0	15
Slope	0.000013	0.005014	0.996	0
Rolling Avg	0.044642	0.657378	0.511007	4
Yield	0.000269	0.088185	0.929738	0
Class 1	0.000908	0.020276	0.983825	0
Class 2	0.000533	0.010417	0.991689	0
Class 3	-0.000033	-0.000556	0.999556	0
Class 4	0.003041	0.003906	0.996884	0
Class 5	-0.056869	-0.960185	0.337068	6
Dist City	0.000927	0.634151	0.526049	15
Dist UGA	-0.000304	-0.04071	0.967531	0
Dist Rive	-0.000191	-0.047907	0.961795	0
Dist Stream	0.00141	0.131781	0.89517	1
Inv Dist City	0.029193	0.042794	0.96587	0
Inv Dist UGA	0.000006	0.123553	0.901681	1
Inv Dist Rive	-0.001001	-0.351012	0.725613	2
Inv Dist	0	-0.00204	0.998372	0
Groundwater	0.024229	0.412568	0.679964	2
Residentail	0.15089	3.797551	0.00015	14
Kittitas	0.597486	8.045166	0	15
Benton	0.245797	3.538911	0.00041	15

Note: Coefficients are weighted by the posterior odds probability and are zero when covariates do not appear in a model. The last column displays the number of times a variable is selected in one of the top 15 models that have at least 15 of the total probability mass. 110,000 initial draws were taken with 10,000 omitted resulting in 100,000 draws.

Table 4: Base Regression

Variable	Posterior Mean	Std Deviation	t-statistic
Senior	0.122015**	0.034335	3.55361
Time	0.019463**	0.003204	6.07511
Time^2	-0.0001**	0.000033	-3.0828
Acres	-0.00263**	0.000345	-7.62564
Improvement	0.000043**	0.000004	11.95061
Rolling Avg	0.193034**	0.068329	2.82506
Class 1	0.248335	0.700075	0.35472
Class 2	0.2519	0.699176	0.36028
Class 3	0.240286	0.699997	0.34326
Class 4	0.74422	1.043965	0.71287
Class 5	0.037268	0.701178	0.05315
Distance City	0.001623	0.001472	1.10269
Distance Stream	0.022726*	0.010716	2.12068
Inv. Distance UGA	0.00011*	0.000051	2.1694
Inv. Distance River	-0.00666*	0.002996	-2.22312
Groundwater	0.155692**	0.057715	2.6976
Residential	0.154672**	0.038647	4.00215
Kittitas	0.614138**	0.076476	8.03043
Benton	0.267071**	0.070776	3.77346
Intercept	5.529015**	0.896351	6.16836

Note: The dependent variable is the natural log of the per acre sale price of a parcel. Class variables represent the percentage of each parcel that falls within that class. Slope is the average slope of the entire parcel. **, and * designate significance at the 1% and 5% level respectively. Posterior distributions are based on a heteroskedastic error term with the degree of heteroskedasticity estimates within the model. 220,000 initial draws were taken with 20,000 omitted resulting in 200,000 draws.

Table 5: County Regressions

Kittitas	Yakima	Benton
0.1135	0.2267	-0.0032
[-0.090-0.3173]	[0.1404-0.3133]	[-0.138-0.1325]

Note: The first row is the posterior mean for the coefficient on a senior water right dummy, and the second row is the 95% highest posterior density interval for that parameter. All controls in the base result are included in the regressions except for the county dummies, which are perfectly multicollinear.

Table A1. MCMC Convergence Diagnostics - Autocorrelations for parameter chains

Variable	Lag 1	Lag 5	Lag 10	Lag 50
Senior	0.129	-0.002	0	0
Time	0.146	-0.003	0.006	0.002
Time^2	0.126	-0.008	0.002	0
Acres	0.189	0.004	0.001	-0.003
Improvements	0.176	0.008	0.008	0.009
Rolling Avg	0.144	0.007	0.003	0.001
Class 1	0.028	0.002	0.002	0.003
Class 2	0.028	0.002	0.003	0.003
Class 3	0.028	0.002	0.002	0.003
Class 4	0.012	0.001	-0.001	0
Class 5	0.029	0.002	0.002	0.003
Distance City	0.126	0.001	0.001	0.001
Distance Stream	0.127	0	-0.003	0.002
Inv Dist UGA	0.142	0.003	0.001	0.002
Inv Dist Yak Riv	0.161	-0.001	0.004	0.003
Right	0.117	0.003	0	0
Residential	0.115	0.001	-0.004	0.001
Kittitas	0.137	0.001	0	0.002
Benton	0.128	0.002	0	0.001
Senior	0.129	-0.002	0	0

Note: Autocorrelation measures of the posterior estimates based on the draws of the Gibbs sampler. 500,000 initial draws were taken with 50,000 omitted resulting in 450,000 draws.

Table A2: Geweke Chi-square Test for Equality of Means

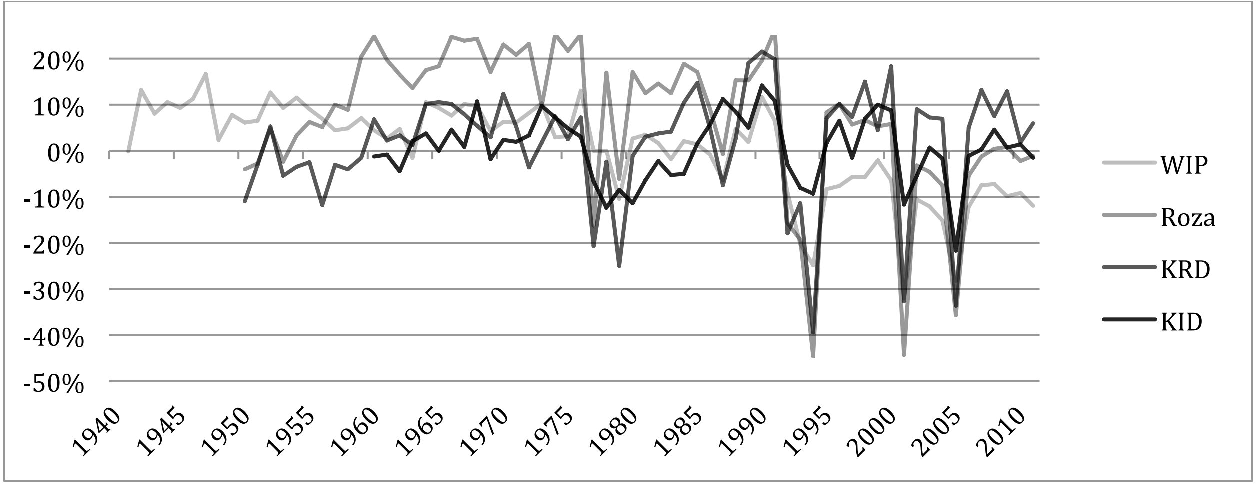
Variable	NSE	NSE 4%	NSE 8%	NSE 15%
Senior	0.8868	0.9231	0.9258	0.9221
Time	0.5542	0.6586	0.6529	0.6123
Time^2	0.7283	0.7314	0.7160	0.6604
Acres	0.8886	0.9201	0.9238	0.9238
Improvements	0.1471	0.4905	0.4748	0.4434
Rolling Avg.	0.8088	0.8693	0.8708	0.8571
Class 1	0.6951	0.7084	0.6804	0.6245
Class 2	0.7780	0.7867	0.7621	0.7191
Class 3	0.7679	0.7744	0.7517	0.7068
Class 4	0.5468	0.5438	0.5388	0.5182
Class 5	0.7487	0.7602	0.7345	0.6910
Distance City	0.4681	0.5105	0.4703	0.3905
Distance Stream	0.8367	0.8584	0.8442	0.8369
Inv Dist UGA	0.6766	0.7290	0.7411	0.7439
Inv Dist Yak River	0.6679	0.6425	0.5978	0.5735
Right	0.6345	0.6199	0.5521	0.4226
Residential	0.8324	0.8646	0.8659	0.8569
Kittitas	0.2728	0.3412	0.3022	0.1148
Benton	0.7977	0.8142	0.8173	0.7860
Intercept	0.7737	0.7627	0.7389	0.6847

Note: Results are p-values for the Geweke chi-square test for difference in means for two intervals of Gibbs draws. I use the first 20% and the last 50% of draws as the two intervals. 220,000 initial draws were taken with 20,000 omitted resulting in 200,000 draws.

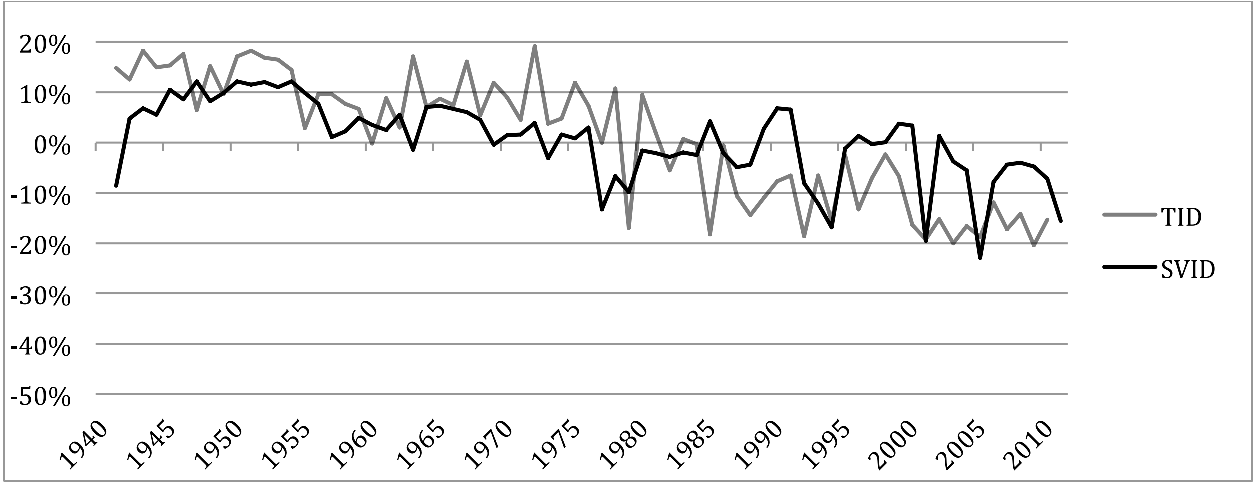
Figures

Figure 1: Annual Deviations from Mean Diversions by District

Panel (a) Junior Rights Districts

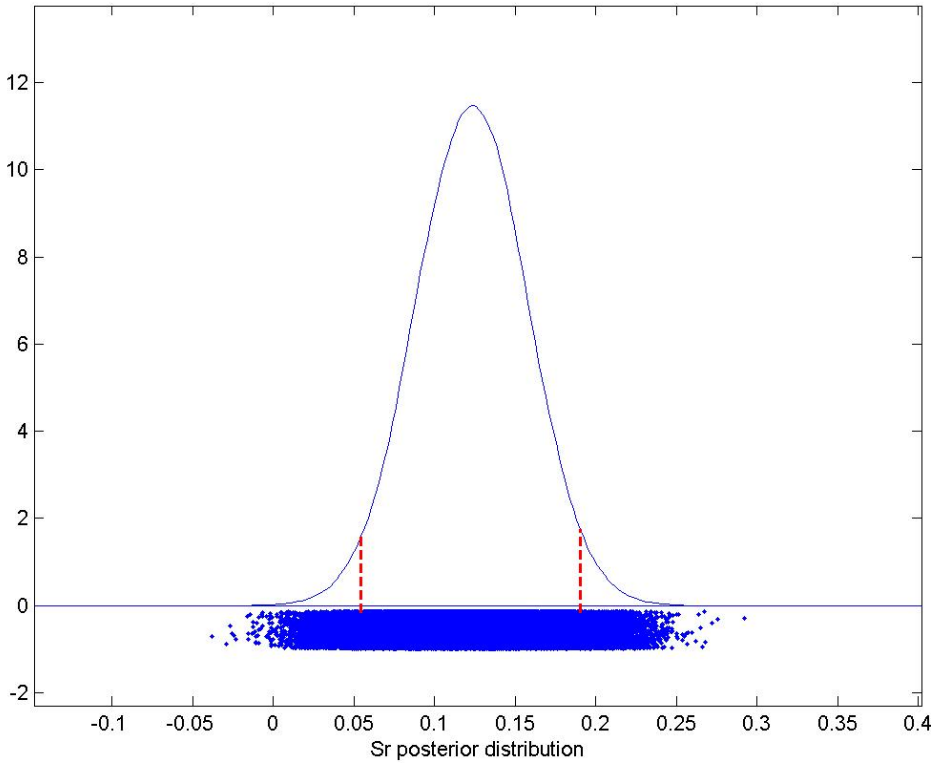


Panel (b) Senior Rights Districts



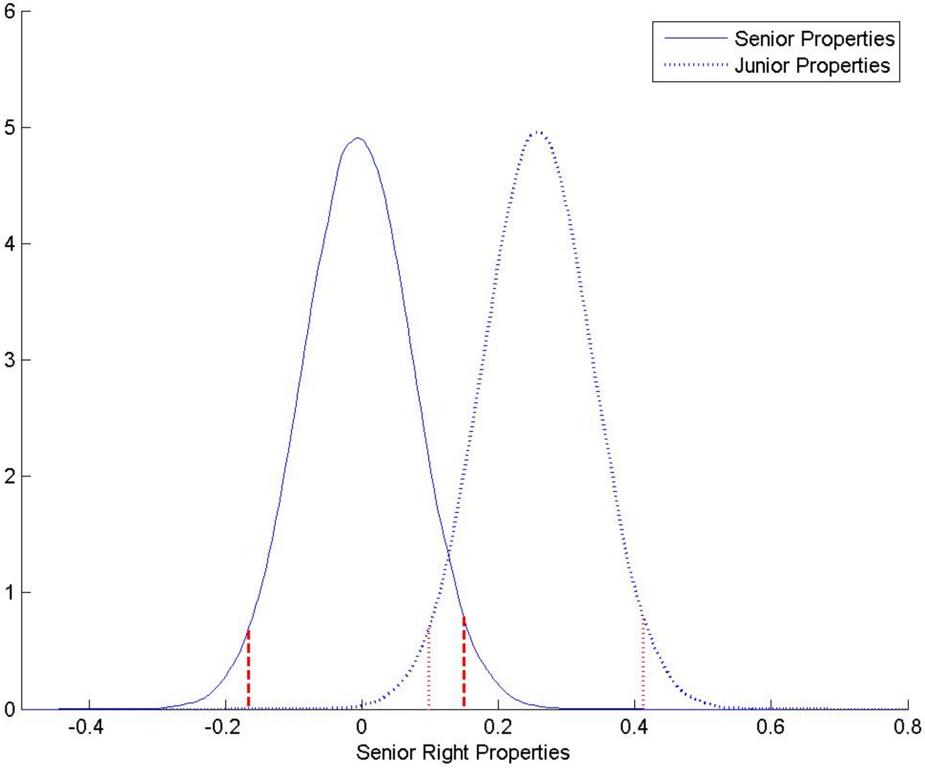
Note: Annual deviations from the mean are shown in percentage terms by irrigation district. TID and SVID are identified as senior district while KRD, Roza and WIP are junior districts based on the Integrated Plan (USBR 2012). Even though KID owns predominantly junior rights it receives recharge water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

Figure 2: Base Posterior Distribution for Sr. Water Right Coefficient



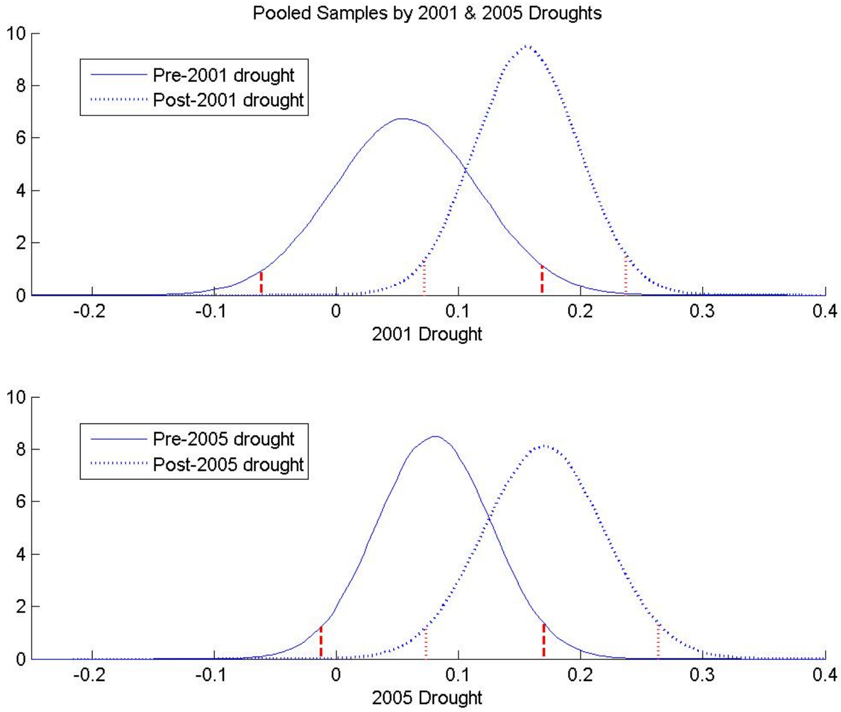
Note: This is the posterior distribution for the senior water right coefficient in the base regression. Additional controls are shown in Table 3. 220,000 draws were taken in the Gibbs Sampler with the first 20,000 discarded. The points at the bottom are the raw draws and the dashed lines represent the 95% highest posterior density interval.

Figure 3: Posterior Distributions for Supplemental Water Right Coefficients



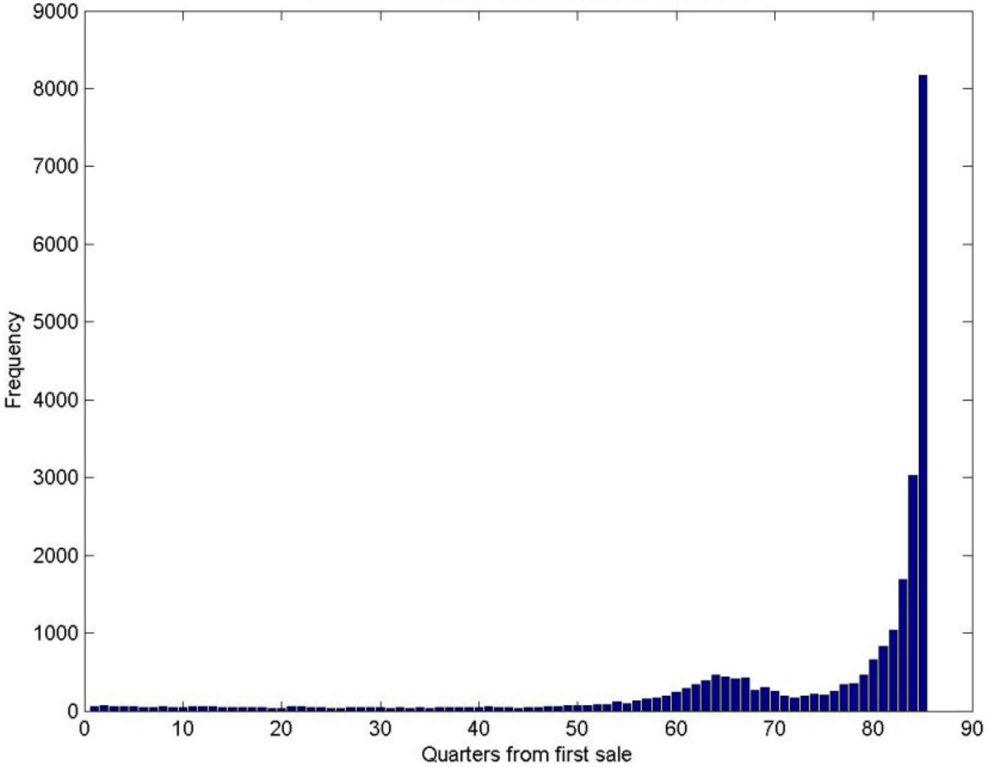
Note: This is the posterior distribution for the supplemental right coefficient with all controls in the Base regression except for senior, since the sample is pooled by senior vs. junior. Posterior distributions are based on 220,000 draws in the Gibbs sampler with the first 20,000 omitted. The distribution with the solid is the based on properties with senior primary rights, and the distribution with the dotted line is based on properties with junior primary rights. Thick and thin vertical dashed represent the 95% highest posterior density interval for the distributions with senior and junior primary rights respectively.

Figure 4: Posterior Distribution for Sr. Water Right Coefficient Pooled by Date



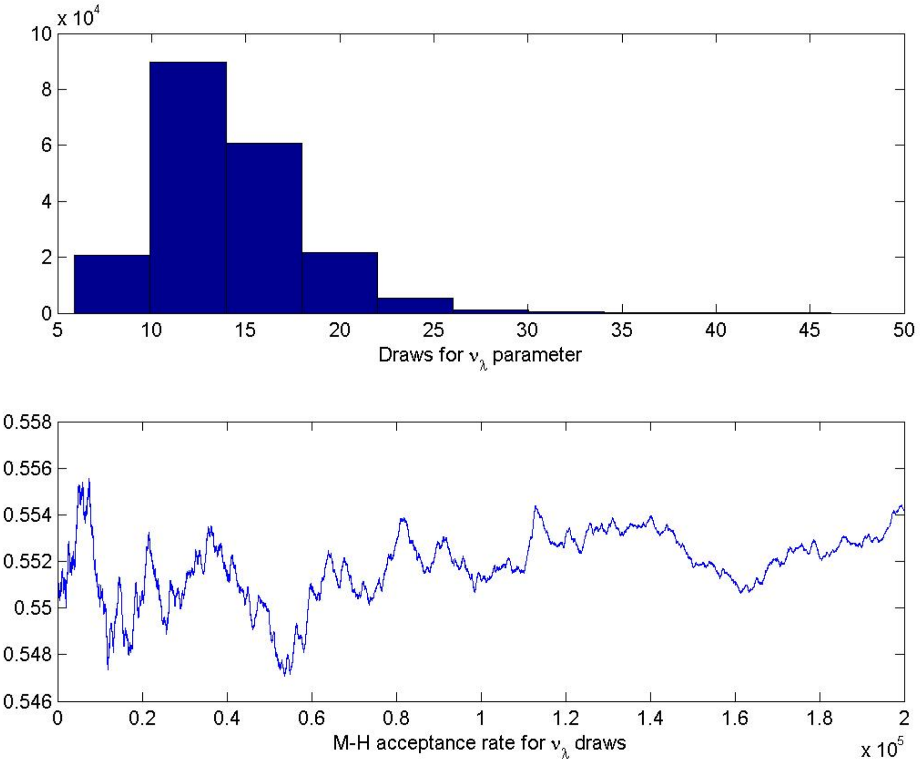
Note: This is the posterior distribution for the senior right coefficient with all controls in the Base regression. Posterior distributions are based on 220,000 draws in the Gibbs sampler with the first 20,000 omitted. The distributions with solid lines in each pane are the based on the sample before the 2001and 2005 drought respectively, and the dotted lines are based on the sample after the drought. Thick and thin vertical dashed represent the 95% highest posterior density interval for the pre and post drought sample respectively.

Figure 5: Posterior Estimates for Changepoint Parameter



Note: Frequency counts for the posterior of the changepoint parameter that determines the quarter where the senior right becomes time-varying. The horizontal axis represents the number of quarters from the first sale in the sample. The control variables are the same as in the base regression model. The first 2778 draws out of 27778 draws of the Gibbs sampler are omitted resulting in 25,000 draws.

Figure A1: Posterior Estimates for Heteroskedasticity Dispersion Parameter



Note: The top panel is a histogram for the draws of the degree-of-freedom parameter, ν_λ, that determines the form of heteroskedasticity in the base regression. The bottom graph shows the acceptance rate for the Metropolis-Hastings algorithm.