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Signs of climate change across the Pacific Northwest indicate changing patterns of timing and availability of stream flow. Declining summer low flows, decreasing snow pack, higher temperatures and an increasing fraction of mountain precipitation falling as rain, raise concerns about future reliability of stream flows. These changes will likely affect the agricultural economy and the balance between in stream and agricultural water uses, requiring a better understanding of how climatic factors and access to water affect farmers' livelihoods and the basin's economy. This study focuses on two economic questions about water and agriculture in the Willamette Valley.

The first question asks: how sensitive is the value of water – as reflected in farmland rents – to variations in temperature, precipitation, soil quality and elevation? The results of a hedonic analysis provide insights into the potential effects of water scarcity that may result from climate change on economic returns to farmers. The second,

related question seeks to understand the factors that affect farmers' decisions to exercise their water rights. Growers in the Willamette Valley do not always use their water rights, a surprising phenomenon compared to other farming regions in the western U.S. The analysis here estimates a logit model of farmers' field-level irrigation decisions. These decisions have quantitatively large implications for the consumptive use of water in the Basin overall.

The relatively low estimated values for irrigation water rights (compared to other agricultural regions) reflect these patterns of intermittent use of those water rights. The comparison, however, between the per acre value of an irrigation water right and the incremental value of precipitation suggest that water has a similar value to farmers whether it comes as a right or as rain.

Right as Rain? The Value of Water in Willamette Valley Agriculture

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Alexey V. Kalinin

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Major Professor, representing Applied Economics

Head of the Department of Applied Economics

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of the Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Alexey V. Kalinin, Author

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (continued)

Page

LIST OF FIGURES

LIST OF TABLES

I. Introduction

Reliability of stream flows and precipitation is increasingly becoming a concern in the Pacific Northwest (PNW). Mounting evidence suggests that effects of climate change are already apparent in declining late summer flows (Praskievicz and Chang 2011), temperature increases (Mote and Salthe 2010), a greater fraction of mountain precipitation falling as rain (Chang and Jung 2010), earlier snow melt (Chang and Jung 2010) and increases in early spring stream flows (Chang and Jung 2011).

The shifting patterns of precipitation and runoff will complicate the management of water supply across different uses. Increasing temperatures and climatic variability together with rising urban populations may simultaneously increase demand for water in agriculture, municipal supply and ecosystem services and recreation. Agriculture in particular may face a complex adjustment to these changing climate dynamics. If summer low flows continue to decline, water availability for irrigation will be increasingly limited at a critical time. Additionally, modification of reservoir operations to maintain lower reservoir levels to guard against increasing flood risk from earlier, faster snow melt could result in decreased availability of stored irrigation water (Hayhoe 2004). At the same time, projected increases in summer temperatures will increase agricultural demand for water.

There is an extensive literature on the response of irrigators to increases in water scarcity, which suggests that farmers adapt by changing their crop mix (Ogg and Gollehon 1989, Moore et al 1994), adapting irrigation (Schuck et al. 2005) or substituting toward water saving technologies (Shoengold et al. 2006) in the long run, and reducing irrigation (Hendricks 2012) or fallowing land (Shoengold et al. 2006) in the short run. This body of work primarily focuses on drier agricultural regions of the US West however, where water is a greater constraint in agricultural production. The current research focuses on agricultural water use in the Willamette Valley, a region considered to be water rich and one of Oregon's most productive agricultural areas, responsible for almost half of the state's gross farm and ranch sales (ODA 2012). The objective of this work is twofold: (i) to better understand the economic implications for farmland value from changes in availability of water as a result of climate change (ii) to characterize factors that affect a farmer's irrigation decision.

The first objective aims to quantify some of the economic effects of climate change on the agricultural economy of the Willamette Valley through analysis of climate change impact on farmland values. Some of the ways in which farmland values can be affected by climate change and that are considered in this paper include loss of irrigation water rights as a result of insufficient stream flows, declining precipitation or increasing temperatures. In addressing the first aim, this paper utilizes the literature on Ricardian farmland rents. An assumption of Ricardian land rent theory is that the annual rental value of agricultural land should reflect its expected profits from the highest-value use of the land, if land markets are competitive and at equilibrium (Mendelsohn 1994). Using observations from a cross section of land rents taken over a range of climatic and land quality conditions, it is possible to assess the effect of changes in those variables on land rents. The first objective is achieved by collecting agricultural land rents data for irrigated and non-irrigated land for all counties in the Willamette Valley and applying the hedonic price method to decompose land rents into contributing values of soil, water rights, temperature, precipitation and elevation.

The second research objective addresses a situation usually not encountered in the irrigation literature: understanding the factors that cause growers to not irrigate on a frequent basis. In most arid agricultural regions of the West, a farmer will use a water right if one is available since land is only marginally productive without irrigation. This is not the case in the Willamette Valley. As a result of greater precipitation in the Willamette Basin, many crops can be grown without irrigation, and as much as 50% of the land that has irrigation rights is not irrigated in a given year (OWRD 2013; USDA NASS 2009). Being able to separate paper irrigation water rights from those actually utilized, and account for the economic value of water is important for understanding the impact of climate change on water availability for agricultural, municipal, environmental and recreation uses. To achieve the second objective, a survey of irrigators was carried out to gather information on irrigation and crop choice decisions at the field level, over 6 years. A field level, time series panel data set for 741 fields, with spatially derived land quality and climate variables was constructed and used to develop a discrete choice model for a farmer's decision of whether or not to irrigate a field. While the objectives are separate questions, they are linked in that the behavior of farmers concerning the choices they make about irrigation should be a reflection of the value of irrigation water as it is capitalized into the price of land.

This paper is organized as follows. Section 2 provides a description of the Willamette Valley. Section 3 is an overview of literature on climate change, farmland valuation, hedonic price method, and irrigation and technology adoption. Hedonic decomposition of farmland rents is presented in section 4 and the irrigation decision model is developed in section 5. Discussion is in section 6, followed by implications and conclusion in section 7.

II. Study Site Description

2.1 Willamette Valley Landscape: Physical Geography and Climate

The Willamette River Basin (WRB) is located between the Cascade Mountains in the East and the Coast Range in the West, covering an area of 29,700 km^2. The Willamette River Basin is characterized by a temperate marine climate, with mild, wet winters and dry summers (Franczyk and Chang, 2009b). Average annual temperature is 11.2 C, with a growing season average temperature of 15 C (April-October) and average January temperature of 4 C (PRISM 2013). Annual precipitation is highly elevation dependent and varies from an average of 45 inches across the agricultural land on the valley bottom (< 300 meters) to 160 inches on the ridges (over 3000 meters) of the Cascade range (PRISM 2013). Precipitation in the valley is highly seasonal, with 90% falling between October and May and only 2.5% in July and August (PRISM 2013).

2.2 Willamette Valley Economy and Demographics

The basin is home to over 2.7 million people, 70% of Oregon's population, and the state's three biggest cities, Portland (population 587,865), Eugene (population 158,335) and Salem (population 156,455) (Population Research Center, 2013). Major sectors in the Willamette Valley economy include the high technology industry, construction, manufacturing, trade and transport of goods, retail, education and health services as well as agriculture and forest products industry, which are more important in rural parts of the valley (UO CSC 2012; USDA 2010).

2.3 Willamette Valley Land Use: Agriculture and Other

The WRB is one of Oregon's most important agricultural regions, contributing $2.3 billion of the $5.3 billion of gross farm and ranch sales in Oregon in 2012 (ODA 2012). As shown in Table 1, the main crop categories among harvested cropland acreage are grass seed (52.7%), hay (15.1%), orchards (5.64%), vegetables (5.43%), field crops (4.47%) and nurseries (4.07). Some of these crops disproportionately contribute to agricultural sales, with nurseries and orchards jointly accounting for only about 10% of the harvested cropland acreage, but almost 50% of the gross sales from crops. Table 2 presents gross sales for the main crop categories (OSU 2011). The average farm size across the valley is 100 acres (USDA NASS 2009).

According to 2006 National Land Cover Database, agriculture occupies approximately 42% of the Willamette Valley floor, defined by land less than 350 meters (1150ft) in elevation. The 42% are split between hay and pastureland (25.4%) and cultivated cropland (16.5%). The rest of the major land cover categories consist of forest (25%) and developed land (15.8%)

Table 1: Major crops and irrigated acreage in the Willamette Valley

Categories of Major Crops	Harvested Acres	Irrigated Acres	Percent Crop Irrigated	Percent of Harvested Acres
Grass and Field Seed Crops	505566	88210	17.45	52.67
Hay, Forage, Silage,	145099	26029	17.94	15.12
Berries	20640	15184	73.57	2.15
Orchards	54138	10841	20.02	5.64
Vegetables	52116	47916	91.94	5.43
Field Crops	42898	5830	13.59	4.47
Nursery	39081	33219	85.00	4.07
Specialty Crops	5825	4723	81.08	0.61

Table 2: Gross sales for major crop categories (OSU 2011).

WV Ag Gross Sales by Crop Group	$ Millions
Grains	87.7
Hay/Forage	66.1
Grass/Legume Seeds	222.5
Field Crops	68.4
Tree Fruits/Nuts	189.3
Vegetables	66.5
Nursery/Specialty Crops	696.1
Undisclosed	74.7

2.4 Water Rights in the Willamette Valley

Of the 959,803 harvested acreage in the Willamette Valley, 275,745 (28.7%) were irrigated in 2007, with an additional 21,606 acres of irrigated hay and pasture, for a total of 297,351 irrigated acres of agricultural land (USDA NASS 2009). According to the database maintained by the Oregon Water Resources Department (OWRD 2013), there are approximately 547, 000 acres of land with water rights in the WV, with 43% of that acreage irrigated by groundwater and 57 % by surface water. Water rights in WV are governed by the doctrine of prior appropriations, where the water right holders with the oldest priority date receive water first and junior water right holders receive water only if it is available. A common feature of prior appropriations doctrine is a “use it or lose it” stipulation that requires irrigators to exercise their water rights at least once in a consecutive 5 year period or face forfeiture of their water right for non-use. While this may be enforced more stringently in the more water scarce Eastern Oregon and other drier parts of the West, there is little enforcement of this rule in the Willamette Valley because of generally sufficient availability of water (Bastasch 1998). Curtailment of water rights has largely not been observed on the main rivers in the valley, although junior water rights holders on some smaller tributaries to the Willamette River experience water rights curtailment almost yearly, as a result of over appropriation of water, environmental flow requirements, and low summer flows (Ken Stahr at OWRD, personal communication, March 2012)

III. Literature Review

3.1 Climate Change Literature

Agriculture in the Willamette Valley, where the majority of agricultural production relies on rainfall to meet crop water demand, is vulnerable to the effects of climate change. Changes in the timing and availability of runoff and precipitation, increases in temperature and incidence of drought can have particularly large effects on the agricultural sector by increasing water scarcity and raising demand for irrigation. An increasing number of studies suggest that these changes are already starting to affect the distribution and availability of water resources across the Pacific Northwest, raising expectations of increasing water scarcity in this historically water rich region over the 21st century.

In a broad look at changes in climate in Western US from 1950 to1999, in regions defined by Cascade, Rocky, Sierra, Blue Mountain, and Wasatch Ranges, together with the Great Basin, Barnett et al. (2008) observed changes in Snow Water Equivalent (SWE) of -2.4 to -7.9% per decade, shifts in river center times (CT) of 0.3 to 1.3 days per decade, and increases in winter minimum temperatures of 0.43 C per decade. These changes are indicative of warmer winter temperatures, a smaller fraction of annual precipitation falling as snow, and peak snowmelt occurring earlier. Regonda et al. (2005) see particularly large responses to climate change in river basins across the Pacific Northwest, observing on average a 10-15 day earlier arrival of spring warm spells relative to 1950, lower Snow Water Equivalent in March, April and May, and corresponding higher spring stream flows and lower summer flows. Changes were most pronounced at lower elevations (< 2500 meters) with mild winter temperatures, where even small increases in temperature can have a large impact on the share of annual precipitation that falls as rain and the timing of spring runoff (Regonda et al. 2005).

Focusing more on annual runoff for the period 1948-2006, Luce and Holden (2009) observe increasingly lower stream flows in dry years. While there were no significant trends in mean annual runoff, in 72% of the 43 stream gauge stations across the PNW, decreases were observed in the 25th percentile annual flows. For half of those gauges, the decrease in runoff exceeded 29%. This points to the importance of considering non stationarity in variance, which could lead to more extreme events even as the means of climate variables remain the same (Luce and Holden 2009, Milly et al. 2008).

Mote and Salthe (2010) present future climate projections for the PNW region relative to baseline 1980's climate parameters using high (A1B) and low (B1) emission scenarios. Using a 20 model simulation of PNW climate the authors predict summer temperature increases of 3- 4.5 C and winter temperature increases of 2.7-3.3C by 2080s. Winter precipitation is predicted to increase by 7.3-7.9 % and summer precipitation to decrease by 11-14.4% by 2080s. While the models predict an unambiguous annual temperature increase, mean annual precipitation does not change significantly, as a result of opposite trends in winter and summer precipitation.

Narrowing the geographic region to the boundaries of the Willamette Valley, several studies make predictions for changes in the valley climate over the 21st century (Jung and Chang 2011, Chang and Jung 2010, Graves and Chang 2007, Praskievicz and Chang 2011). Consistent with regional observations of lower summer flows and higher winter flows, Praskievicz and Chang (2011) predict that summer flows of the Tualatin River will decrease by 20-40% throughout summer months and winter and spring flows will increase, 4-7 % relative to the baseline years of 1970 to 1999. Additionally, Praskievicz and Chang (2011) predict a greater soil moisture deficit as potential evapotranspiration increases as a result of decreasing precipitation and increasing temperatures.

Modeling the Upper Clackamas River Basin, located southeast of Portland, OR, Graves and Chang (2007) predict a decline in the percent of precipitation falling as snow, from 26% during baseline period to 14% by the 2080's, increase in average annual temperature of 3.3-3.7 C by 2080 and increase in annual precipitation of 12-27% by 2085 primarily as a result of greater winter precipitation. Graves and Chang also expect large declines in the snowpack, 36-49% by 2040 and 83-88% by 2100 and a corresponding 18-28% decline in summer low flows relative to 1971-2000 baseline.

In a study covering the entire extent of the Willamette Valley, Chang and Jung 2010 use an ensemble model approach with eight global climate models to make predictions about changes in Willamette Valley climate and hydrology across its 218 subbasins. Average annual precipitation is predicted to increase by 1.1-3.4% by 2080, with a 6% increase in winter precipitation and a 16-22% decrease in summer precipitation, while average annual temperature is predicted to increase by 2.4-3.4 C. As a result of higher temperatures, earlier onset of snowmelt and decreasing amount of precipitation falling as snow, the center timing of streamflow will occur 3-10 days earlier by 2080, with a greater shift in higher elevation basins that are more affected by changes in snow melt dynamics. Chang and Jung (2011) also expect decreases of 5-15% in seven day low flows and increases of 3-8% in top 5% flows, with the greatest changes occurring in watersheds at higher elevations.

3.2 Economic Value of Land

Before investigating the sensitivity of farmland value to various characteristics of the land, it is important to examine the conceptual model for farmland value and answer the following question: what are the determinants of farmland value? The study of land value is based on the theory of land rents, first developed by David Ricardo. In Ricardian rent theory, rent is the profit that accrues to the landowner from the highest value use of his land, the difference between gross revenues and costs (Ricardo 1821). In rural areas, the highest value use for land is often in agriculture. Ricardo argued that agricultural land rents arise from the fixity of land as an input for agricultural production and differences in the location and productivity of land. The most fertile land, with lowest production costs and closest location to markets yields positive rents relative to marginal land, for which production costs equal revenues, rent is zero and the farmer indifferent about growing crops on that land (Ricardo 1821). The rent differential is fundamentally a result of scarcity of good quality land, and it arises when marginal land is brought into production. If an infinite amount of good quality land was available for anybody interested in farming, there would be no rent. As a result of scarcity however, farmers are willing to pay rents to have access to good quality land.

Rents vary not only across land of differing quality, but also among different uses for the same land. For example, use of land for urban development may be a higher value use than agriculture. A parcel of agricultural land close to a city and affected by demand for urban services will have higher rents than comparable agricultural land without development potential, and would be converted out of agriculture by a profit maximizing land owner.

More generally, assuming that land owners are profit maximizers and employ their land in its highest value use given the constraints on their land (e.g., land use regulations), that markets for land are competitive with many buyers and sellers, and that land prices are in equilibrium and reflect long run climate and market conditions, land rents will be equal to the expected profits from land (Mendelsohn 1994). Correspondingly, the price of land equals the discounted sum of all future annual rents, which means the potential profits from agricultural and non-agricultural land uses are capitalized into the price of land.

3.3 Land as a Differentiated Factor of Production

An extensive literature on land valuation has emerged to analyze land prices and identify the effect of constituent characteristics of land on its value. The general approach has been to treat land as a differentiated factor of production that has a bundle of characteristics, and model implicit prices of its characteristics using Rosesn's (1974) hedonic method. Palmquist (1989) provides a theoretical framework of the hedonic method in application to farmland, which is briefly reviewed here.

Plots of farmland have a number of characteristics that vary between parcels. Some of these characteristics cannot be changed, like the climate, soil type and topography of the land, while others can be changed in response to market conditions. For example, one can install irrigation, build structures and change drainage properties of the land. The rental price of the land (P) is a function of those characteristics (q), and can be modeled as a hedonic equation $P = (q_1, q_2, \ldots, q_n)$. It is assumed that the hedonic price schedule is determined by the interaction of many buyers and sellers in the market and that no one individual demander or supplier of land can affect the equilibrium price schedule. A landowner can however alter some of a parcel's characteristics, changing the rental price of a parcel.

Farmers act to maximize variable profits on a plot of land, and make bids for land that depend on the characteristics of the land, prices of outputs and inputs, a farmer's desired profit level and farmer's production skills. If the land market is in equilibrium, an increase in a farmer's bid for land following a marginal increase in one of the characteristics of land must equal the corresponding increase in the rental price of that land. If this was not the case, a farmer could increase profits by using land with different characteristics. Additionally, the farmer's bid for land must equal the rental price of land, to abide by the zero profit constraint. Landowners similarly act to maximize profits from renting a parcel of land, accepting market set prices for land characteristics they cannot control and equating prices for characteristics they can control to market prices for those characteristics. In this way, both farmers and land owners accept a parametric price schedule that is determined by the interaction of suppliers and demanders of land in the market place, with the price schedule changing to clear excess supply or demand in the market.

The supply of land for farming is not fixed, because land has alternative uses. The rental price of land in alternative uses, for example forestry, or pasture, presents a lower threshold limit for the rental price required to keep the land in agriculture. If rents fall below that price, land will be taken out of agricultural production and converted to the next most profitable use. Similarly, returns to agriculture may increase, and land that was previously not suitable for agricultural use may be converted to agricultural production. It is also possible that land rents can increase as a result of development pressure or other non-agricultural regions, which may lead to conversion of land out of agriculture to a higher value use.

Within the framework of the hedonic analysis of land rents, it is possible to estimate changes in welfare that result from changes in land characteristics using the hedonic price schedule. If the change affecting land characteristics is localized and does not shift the hedonic price schedule, a change in capital gains for those parcels can be computed from the hedonic function. If many parcels are affected and the hedonic price schedule shifts as a result, a calculation of a change in welfare is still possible, by deriving a farmer's willingness to pay for a change in land characteristics from his profit function (See Palmquist 1989 for details). In both cases, estimates of welfare change depend on the assumption that input and output prices do not change, making this a partial equilibrium analysis (Maddison 2000, Schleker et al. 2004).

3.4 Sensitivity of Land Value to Water Availability

Irrigation water is a key input in crop production, particularly across much of the U.S. West, where absent irrigation even good quality land can be reduced to marginal productivity. The price of water may convey important information about regional scarcity of water, and can help to explain the behavior and choices of farmers with respect to their water use decisions as well as approximate the magnitude of welfare change that may result from a decline in water availability. Although fully-developed water markets are rare in agriculture, in some areas, the price of water may be directly observed from water market transactions. If there is limited information on water market transactions like in the Willamette Valley, alternative methods can be used to derive the value of water. Given that availability of water is represented by a water right that is tied to land, or the amount of precipitation, the value of water will be capitalized into the price of land and thus could be derived using a hedonic price decomposition approach, taking advantage of variations in land characteristics and property values.

Many studies have examined land prices to identify determinants of land value using hedonic approaches, although there have been only a few that considered the sensitivity of farmland value to availability of water and changes in climatic variables (Butsic and

Netusil, 2007; Faux and Perry 1999, Hartman and Andersen 1962; Petrie and Taylor, 2007; Torrell et al. 1990; Yoo et al. 2013). These studies generally use data on land sale transactions and characteristics of the land to derive the value of water, with all studies finding that water availability significantly contributes to land value.

These studies utilize similar functional forms, using either linear (Torrell et al., 1990; Hartman and Andersen 1962; Faux and Perry, 1999) or semi-log (Petrie and Taylor, 2007; Butsic and Netusil 2007; Yoo et al., 2013) models, but differ in the approaches for deriving the value of water. Faux and Perry (1999) included the values for irrigated and non irrigated land in one regression, determining the value of water by soil class from the difference between those coefficients. Hartman and Anderson (1962) include the number of irrigation company shares that are sold with the land into their linear model, calculating per acre foot price based on average deliveries per share. Butsic and Netusil (2007) included a dummy variable in their hedonic model if farmland had a water right, identifying the value per acre foot based on maximum seasonal diversions allowed for those water rights. Petrie and Taylor (2007) take advantage of a moratorium on development of new irrigation rights, comparing the differences between land values of irrigated and non irrigated land, pre and post moratorium. They find prices per acre foot by calculating average local irrigation requirements. Torrell et al. (1990) obtain groundwater aquifer characteristics in addition to farmland sales transaction data, decomposing farmland value to determine the contribution of water available in groundwater storage to the sales price. Yoo et al. (2013) directly include the number of acre feet attached to a groundwater irrigation right into their regression. See Table 3 for a summary of water prices and geographical areas represented by the studies.

Table 3: Summary of hedonic water right studies

Study	Water Price $/acre foot	Location	Functional Form
Hartman and Andersen (1962)	$30	Big Thompson Irrigation Project, Colorado	Linear
Torrell et al. (1990)	$3.93	Ogallala Aquifer Region	Linear
Faux and Perry (1999)	$9-44	Malheur County in South Eastern Oregon	Linear
Butsic and Netusil (2007)	$5-26	Douglas County, in South Western Oregon	Semi-Log
Petrie and Taylor (2007)	$36	Dooly County, Georgia	Semi-Log
Yoo et al (2013)	$11-90	Phoenix area, Arizona	Semi-Log

Important explanatory variables used in these studies included soil quality, climate variables, value of improvements on land, parcel size, and indicators of development pressure, although there was substantial variation in variable choice. Soil quality, often represented by land capability class (LCC), an index of various soil quality parameters with 1 being the best farmland and 8 being rocky outcrops, was found to be very significant in explaining the value of farmland (Petrie and Taylor, 2007) and water (Faux and Perry, 1999). The value of an acre foot of water increased with soil quality (Faux and Perry, 1999). Only Torrell et al. 1990 included a measure of climate, using precipitation data. Precipitation was highly significant, adding $57.10 per acre to dry land farm value per additional annual average inch of rainfall. Parcel or farm size were very significant and when interacted with water rights show that irrigation becomes less valuable in terms of per acre value as farm size increases (Yoo et al., 2013; Butsic and Netusil, 2007). Distance to a local population center has been shown to have a negative effect on land value (Faux and Perry, 1999; Butsic and Netusil, 2007), although the significance of this variables may depend on the local economy and the extent to which agricultural land prices are affected by urban development.

Development pressure also appears to have a substantial effect on water prices. A measure of development pressure was included by Yoo et al. (2013), who computed percent developed land within a 3 km radius of a farmland parcel. They found that willingness to pay for an additional acre foot of water attached to a water right was more than twice as high on farmland where neighborhood land was developed.

3.5 A Farmer's Utility from Irrigation

A discussion of a farmer's irrigation decision is presented in this section to consider how a farmer may approach the decision of what crop to plant and whether or not to irrigate a given field. Farmers generally own multiple fields and each year make decisions regarding crop and irrigation choices for those fields. As a farmer deliberates possible crop and irrigation choices for a given field, it does not seem plausible that he would decide to first plant a crop and then choose whether or not to irrigate it, or conversely, decide whether or not to irrigate a field and then choose a crop. The crop and irrigation choices are most likely determined simultaneously, and the decision is a function of land attributes, climate, input and output price levels, personal characteristics of the farmer and the production decisions the farmer made on other fields.

Farmers are assumed to maximize their profits. While irrigation can increase profits through higher yields for crops and expand the range of crops that could be produced, it also results in higher costs from additional labor and operating expenses to manage the irrigation system. Since farmers are heterogeneous in their production skills and in the attributes of their land, the additional benefits may justify irrigation for some farmers but not for others. As a farmer considers a portfolio of irrigated and non-irrigated crops to choose from for his fields, his profit maximizing option might be to choose some crops from of each category and this choice may vary from year to year depending on the climate and market that year as well as the farmer's personal circumstances. Anecdotally, in addition to variables like climate and land quality that can be observed, a lot of unobservable factors may influence a farmer's crop choice and irrigation decision and lead it to vary from year to year. For example, whether or not irrigation equipment is already set up on a given field or requires additional work to assemble and manage it. Depending on how much help a farmer has in a particular year, it may or may not be worthwhile for him to set it up. Family tradition of growing crops in a certain way also can play a role as well as a farmer's age, education and income. Figure 1 illustrates the tradeoffs in profits a farmer faces in choosing between irrigated and non-irrigated crop. Over a certain range of conditions an irrigated crop is more profitable, but an unirrigated crop can be more profitable otherwise (as illustrated in Figure 1).

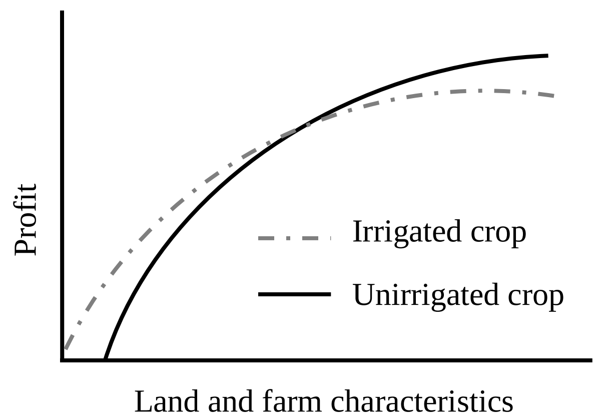

Figure 1: Hypothesized profits for irrigated (solid line) and unirrigated (dotted line) crops

3.6 Irrigation Adoption

A surprising side of irrigated agriculture in the Willamette Valley is that growers do not always use their water rights, a contrast to other farming regions in the western U.S. A comparison of irrigated acreage of agricultural land between the 2007 Census of Agriculture and an irrigation water rights database maintained by the Oregon Water Resources Department suggests that only about half of the existing irrigation water rights are being used on an annual basis. As a result, it is unclear which of the existing water rights are active, and what land is being irrigated, making it difficult to quantify actual agricultural water usage in the Willamette Valley. A model of farmer behavior concerning the irrigation decision could yield greater understanding of the observed patterns of irrigation, provide a basis to quantify the amount of water used for irrigation and help to develop a more nuanced understanding for the importance of water to the agricultural economy. To provide a foundation for development of an irrigation decision model, this section reviews literature on the behavioral responses of farmers to changes in the cost of irrigation and irrigation adoption to establish the variables that could influence a farmer's irrigation decision.

There is a well-developed literature on irrigation adoption that has broadly established the effects of water price, soil quality, groundwater depth, topography, climate and drought on adoption of irrigation technology. As water price increases irrigators respond by fallowing land or turning to deficit irrigation in the short run and adopting more efficient irrigation technologies, and changing their crop mix in the long run (Shoengold et al. 2006; Moore et al., 1994). These responses are rational behavioral changes of profit maximizing farmers as a result of a decrease in profits from irrigation. While farmers are limited in the management and land allocation changes they can make in the short run to adapt to new water prices, in the long run they can change their crop mix and irrigation technology to optimize water use under the new price. Price elasticity of demand for water provides an important measure of farmers' capacity to make changes in their water and land allocation decisions as the price of water changes. Demand for irrigation water has frequently been reported to be inelastic (Ogg and Gollehon, 1989; Moore et al., 1994; Hendricks and Paterson 2012). Scheierling et al. (2004) summarize elasticity estimates from 18 studies, finding a range from -0.002 to -1.97, with a mean of -0.51 and a median of -0.22. They observe more elastic estimates at moderate prices of water, when there is greater ambient precipitation, and when a longer time period is considered which allows for greater substitutability at the extensive margin. Studies that focused on annual crops were also more likely to find a more elastic response to water price, since perennial crops require a long time to establish and require a greater capital investment, reducing potential for adjustment to water prices

There has been some criticism in the water demand and irrigation adoption literature for fixation with the volumetric price of water which is a broadly available metric and an important variable in California's San Joaquin valley but not elsewhere (Schuck et al. 2005). Across Western states, many irrigators own water rights individually or collectively, in instances of mutual share ditch companies, and don't pay for water volumetrically. Irrigators either divert water themselves from streams, pump groundwater, or only pay a fraction of the delivery cost from a ditch company or irrigation district (Schuck et al. 2005). In such cases where a volumetric price of water has not been available, the cost of pumping groundwater (Hendricks and Paterson 2012, Ogg and Gollehon 1989), or the percent of normal volume of water delivery (Schuck et al. 2005) have been used as proxies for water price. As groundwater depth increases, or energy prices raise the cost of pumping, irrigated acreage has been shown to decrease and price elasticities in the range discussed above have been observed (Hendricks and Paterson 2012, Ogg and Gollehon 1989).

Soil quality has consistently been found as one of the most significant drivers of cropping patterns (Lichtenberg1989) and adoption of irrigation technology (Negri 2005, Negri and Brooks 1990). Common metrics for soil quality are water holding capacity (Lichtenberg 1989; Negri Brooks 1990), permeability (Shoengold et al. 2006; Moreno and Sunding 2005), texture (Lichtenberg 1989; Moore et al 1994; Negri et al. 2005), capability class (Moore et al 1994, Moore and Negri 1992) and slope. Broadly generalizing, very clayey and very sandy soils are less likely to be irrigated, due to large increases in crop water demand on sandy soils and drainage issues with clayey soils (Negri et al 2005). However, in a moderate range of soil texture, soils with a lower water holding capacity are more likely to be irrigated (Negri and Brooks 1990). Also, probability of adoption of more efficient irrigation technology decreases with increasing soil quality on low gradient soils, since prime land can achieve greater irrigation efficiency even with less efficient technology (Green and Sunding 1997, Moreno Sunding 2005).

Important climate parameters used in irrigation studies include measures of temperature such as annual average temperature (Shoengold 2006) and days over 90 F (Negri 2005), measures of precipitation such as monthly precipitation and days of precipitation exceeding 0.1 inches (Negri 2005), growing season precipitation (Moore et al. 1994), effective annual precipitation or moisture actually available to plants (Moore and Negri 1992) and measures of growing season length like frost free days (Shoengold 2006), cooling degree days (Moore et al 1994), growing degree days (Moore and Negri 1992). The climate variables have been found to be very significant in explaining crop allocation according to plant temperature, precipitation, and growing season length requirements (Moore and Negri 1992, Moreno and Sunding 2005) and appropriate irrigation technology. Negri (2005) cautions however that it is important to consider more than the first moment of climate variables, and take into account the effect of changing variance which has a more significant effect on incidence of extreme events than changes in the mean alone.

A common approach in the irrigation and technology adoption literatures has been to assume that crop choice is exogenous, and use either a multinomial logit model with crop choice as a right hand side variable or condition irrigation technology on crop choice (Moreno and Sunding 2005). There is endogeneity in those choices however, since the irrigation technology and crop are simultaneously determined as a function of land quality, water availability, climate, farm size along with economic and demographic variables. Substitution of crops under one kind of irrigation technology will be different from another, since not all crop and irrigation technology pairs are suitable. Joint modeling of crop and irrigation technology adoption has been proposed as a way to overcome the endogeneity bias (Moreno and Sunding 2005, Shoengold et al. 2006). Moreno and Sunding (2005) use a nested logit approach while Shoengold et al. 2006 use an approach resembling two stage least squares.

IV. Value of Water

With predictions of changing climate and increasing climate variability for the Willamette Valley, it is important to consider the effects of these changes on farmland productivity and the corresponding economic returns to farmers from their land.

Farmland productivity is primarily a function of land quality, climate and availability of water which are reflected in the value of farmland (Maddison 2000, Mendelsohn and Dinar 2003). As patterns of temperature, precipitation and availability of water change due to climatic drivers, the productivity of the land will be affected, and this change will be reflected in the value of the land.

In this section, a hedonic model of the farmland rental value is developed using the framework of the Ricardian farmland valuation approach outlined by Mendelsohn et al. (1994). The approach is based on the assumption that land value is the net present value of future rents from the highest value use of the land. Cross sectional variation in land values is used to determine the implicit value of land characteristics, taking into account the land allocation choices farmers make across a range of land attributes. The hedonic model incorporates soil quality, elevation, precipitation, temperature, and irrigation water availability as explanatory variables for farmland rents. By decomposing farmland rents into individual contributing factors, it is possible to represent the spatial heterogeneity of economic returns to agricultural land use, and observe how they vary as a result of changes in temperature, precipitation and availability of irrigation water.

This section is organized as follows. Subsection 4.1 describes the Ricardian approach to farmland valuation. Subsection 4.2 presents farmland rents data and the variables that land rents are determined by. Subsection 4.3 details how the data set used for the hedonic analysis was derived from tax lot data. Subsection 4.4 outlines the specification of the hedonic model. Subsection 4.5 presents a discussion on expected signs and magnitudes of the coefficients. Subsection 4.6 presents results of the hedonic analysis of farmland value.

4.1 Ricardian Approach to Farmland Valuation

A Ricardian analysis of land value is not fundamentally different from the hedonic price method which is based on the treatment of land as a differentiated factor of production as discussed in section 3.3. A differentiating characteristic is in that Ricardian analysis assumes that farmers are profit maximizers and will make adjustments in land allocation to keep land in its highest value use across any range of land characteristics (Schlenker et al. 2006). Based on these assumptions, and observations of a cross section of land rents for parcels with varying land attributes, it is possible to estimate difference in land value in response to changes in the dynamic characteristics of the land, like climatic or water availability variables (Mendelsohn et al. 1994). Figure 2 demonstrates this, showing a farmer's profit maximizing land allocation decisions in response to changing climate conditions, with those changes reflected in the rental value of his land under different uses.

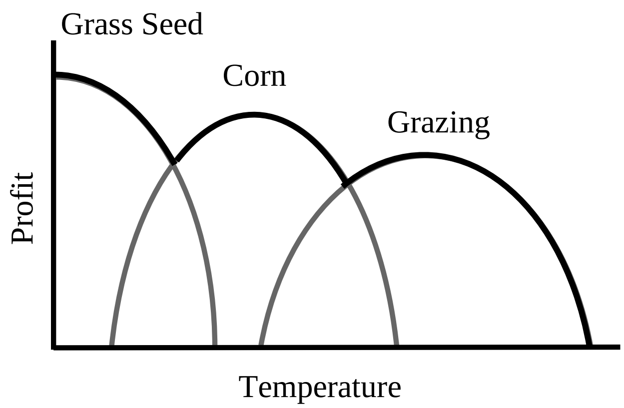

Figure 2: Best use value function for land

Under some initial temperature regimes, the farmer may see the highest profits (land rents) from planting grass seed. As temperature increases, profits from planting grass seed decline, and instead of continuing to plant grass seed the farmer will eventually switch to his next best option, which may be corn. Eventually the farmer will allocate his land to grazing as temperature continues to increase. The bold line in Figure 2 represents the best use value function of the land, tracing the highest profits that a farmer can achieve under a given temperature or other climatic variable. Ricardian analysis posits that through cross sectional observations of land rents, it is possible to derive the best use value function for farmland, and consequently estimate the effects of changes in land characteristics, like climatic variables or the availability of water, on land value (Mendelsohn et al. 1994).

The Ricardian analysis was based on estimates of average farmland rents data for multiple agricultural zones across all counties. The average rent estimates varied by soil and irrigation attributes of a tax lot in each agricultural zone. Elevation, precipitation and temperature data were also calculated for the taxlots and the cross sectional variation in rents across county agricultural zones was used to determine the implicit value of different soil classes, water rights, precipitation and the effect of temperature and elevation on land rents. This is a novel methodology for exploiting cross sectional variation of land attributes for farmland value analysis. Previous studies either used observations of land sale transactions and parcel level data for explanatory variables (Butsic and Netusil, 2007; Faux and Perry 1999, Petrie and Taylor, 2007), or aggregated county level farmland values from Census of Agriculture and county level explanatory variables (Mendelsohn 1994; Schlenker et al. 2006). The approach used here avoids the detailed data requirement typical for hedonic studies and provides better resolution than county level analysis, allowing for effective analysis of farmland value over large areas. Sections 4.2 through 4.4 present the details of data collection and model specification of this approach.

4.2 County Farmland Rents Data

Hedonic analysis of agricultural land rents was carried out using estimates of average land rents obtained from county tax assessor's offices across the Willamette Valley and spatial datasets obtained from several different sources. Average agricultural land rents were computed by counties on a per acre basis to reflect annual land rents by soil class[1],

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[1] Soil class otherwise known as land capability class (LCC) is a primary indicator of land quality. It is an index that incorporates landscape location, slope, soil depth, soil texture, and soil chemical properties. The LCC index ranges from 1 to 8 with class 1 soils being most suitable for agriculture and class 8 representing rocky outcrops. Typically, soil classes 1-4 are used for cropland, and classes 5-8 are used for pasture or woodland (Land Capability Classification)

agricultural zone, landform (i.e. floodplain, terrace, hills) and the presence or absence of water rights. In the land rents data, counties provided average per acre land values for irrigated and un-irrigated land on class 1-4 soils, and land values for non irrigated class 6 and 7 soils. There are negligible acreages of class 5 soils in the Willamette Valley data.

Land rents are estimated by county governments for tax purposes, through surveys of farmers to assess the rental value of agricultural land of varying quality, with and without water rights. Land rents in our sample are estimates for 2011. County land rents represent average land rents across broad regions of the county which for some counties were defined by agricultural zones, land forms or both. Agricultural zones were county areas indicated to have distinctly different agricultural productivity, for example east and west zones of Benton County, characterized by flat valley land and hilly shoulder slopes of the coastal range respectively. Landforms included floodplains, hill slopes and terraces, where land productivity varied by different soil types associated with those landforms, as well as with slope and elevation.

4.3 Selection of Land Parcels and Calculation of Land Rents

While hedonic studies of farmland typically rely on land sales transactions for property attributes that are used as explanatory variables to predict farmland value, a different approach was used in this study to estimate rental values of parcels. Tax lots in agricultural land use from county cadastral data were used to represent property boundaries, with their land quality, climate and water right characteristics representing the parcel attributes. Subsequently, land rents corresponding to the soil and irrigation characteristics of the tax lot were assigned to each parcel.

To generate a data set of agricultural tax lots spanning the extent of the Willamette Valley, cadastral and zoning tax lot data were collected from individual counties and merged together. Tax lots zoned for urban uses or uses otherwise incompatible with agricultural and natural resource use were excluded from the data set. Small tax lots less than 10 acres were likewise excluded to avoid rural residential lots. Remaining tax lots were predominantly zoned for exclusive farm use or mixed forestry and agricultural land use.

USDA Crop Scape agricultural land cover data were used to screen tax lots, to ensure that they were in agricultural use. Only those tax lots that had an average of 80% of their area in crop cover in 2008, 2010, 2011, and 2012 were selected. Those years were chosen to represent a range of economic conditions that could have affected cropped acreage. Additionally, a tax lot area cutoff of 350 acres was imposed, to avoid selecting outlier agricultural fields, given that average farmland size for Willamette Valley was reported to be about 100 acres in the 2007 Census of Agriculture. This procedure provided a sample of 21,721 tax lots.

Zonal statistics in ArcGis were used to attribute agricultural zones, landform type, soil and water rights data to the tax lots. Agricultural zones data was collected from each county in the Willamette Valley for the counties that had more than one zone. Agricultural zones were represented as polygon areas. Landform and soils data were derived from the USDA Soil Survey Geographic Database (SSURGO). Landforms were delineated as areas of floodplain, hill slope and terrace soils. Soils data consisted of polygons for class 1 through class 8 soils, referred to as soil or land capability classes (LCC). Water rights data was obtained from the Oregon Water Resources Department and is in the form of polygons that overlay all lands for which irrigation rights have been issued. Resulting attributes for each tax lot indicated the number of irrigated and non-irrigated acres of each soil class, what agricultural zone it belonged to, and what landform type and agricultural zone the tax lot belonged to. These attributes were used to assign an annual farmland rent value to a tax lot, representing the sum of all irrigated and non-irrigated acres of soils. Climate and elevation variables were also added as tax lot attributes. Climate data consisted of average minimum growing season temperature in degrees Celsius (April-May) and cumulative growing season precipitation in inches. These layers had resolution of 4 km and were derived from the database on 30 year average climate conditions (1981-2010) maintained by the PRISM Climate Group of Oregon State University. Elevation data with 10 meter resolution was obtained from the

USDA GeoSpatial Gateway, a clearinghouse of county and state level spatial data. The resulting data set was used for hedonic analysis where the land quality, elevation, climate and water right variables served as predictor variables, while the land rent data was the dependent variable. Table 4 presents the variables used in the hedonic analysis.

Table 4: Variables used in hedonic model

Variables	**Definition**
Soil Class1	Acres of unirrigated Land Capability Class 1
Soil Class2	Acres of unirrigated Land Capability Class 2
Soil Class3	Acres of unirrigated Land Capability Class 3
Soil Class4	Acres of unirrigated Land Capability Class 4
Soil Class6	Acres of unirrigated Land Capability Class 6
Soil Class7	Acres of unirrigated Land Capability Class 7
Irrigated Soil Class1	Acres of irrigated Land Capability Class 1
Irrigated Soil Class2	Acres of irrigated Land Capability Class 2
Irrigated Soil Class3	Acres of irrigated Land Capability Class 3
Irrigated Soil Class4	Acres of irrigated Land Capability Class 4
DemeanElev	Demeaned elevation (meters)
DemeanPrecip	Demeaned cumulative growing season precipitation (inches)
DemeanTemp	Demeaned average growing season minimum temperature (degrees C)
DemeanElev*Acres	Interaction of demeaned elevation with acres
DemeanPrecip*Acres	Interaction of demeaned precipitation with acres
DemeanTemp*Acres	Interaction of demeaned temperature with acres

4.4 Hedonic Model Specification

A linear ordinary least-squares model was chosen for the hedonic decomposition of land rents, following previous hedonic water value studies. Information on soil quality was utilized in the most spatially distributed way our data allowed, identifying irrigated and non irrigated acres of each soil class within a parcel. Faux and Perry (1999) suggest that including data on individual soil classes provides more information than a combined soil index like a weighted average of soil classes. Elevation, growing season precipitation, and minimum average temperature were included to describe physical and climatic conditions affecting farmland. These variables were demeaned, meaning the sample average for each variable was subtracted from each parcel observation of elevation, precipitation and temperature, to center the climate and elevation variables on the origin. This was done to facilitate interpretation of the coefficients at the mean values, and reduce the effects of the non-linearity in the data on the mean parcel. Expected values of the demeaned variables are equal to zero, and the coefficients for those variables reflect the effect of a marginal change in the variable levels on farmland rental value. Interactions were also included between the demeaned climate and elevation variables with tax lot size, since the effects of changes in those variables should not remain the same between large and small tax lots. This model provides estimates of rent of each irrigated and un-irrigated soil class and the variation in land rents with precipitation, elevation and temperature. Land rents for a tax lot can be expressed as:

$$P = \beta_0 + \sum_1^{16} \beta_j X_j + \varepsilon$$

where P is the parcel rent (per acre per year), β_0 is the intercept, X_j represents the variables in Table 4 that affect land rents and β_j is the coefficient on X_j. Only linear specifications for variables were included. While previous hedonic studies had reported non-linear interactions between land value and precipitation and temperature variables (Mendelsohn et al. 1994, Schlenker et al. 2005) the land farmland rents and climatic data for the Willamette Valley did not support a non linear specification. This may be a result of limited variability of temperature and precipitation variables across the valley compared to national (Mendelsohn et al. 1994) and state wide (Schlenker et al 2005) studies. Table 5 provides summary statistics for model variables.

Table 5: Summary of hedonic model variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Soil Class1	21721	1.15	5.86	0	145.94
Soil Class2	21721	14.77	22.30	0	277.00
Soil Class3	21721	9.69	19.67	0	279.82
Soil Class4	21721	8.09	20.54	0	329.46
Soil Class6	21721	2.64	10.47	0	185.42
Soil Class7	21721	0.24	2.82	0	165.65
Irrigated Soil Class1	21721	1.07	7.077	0	188.54
Irrigated Soil Class2	21721	9.95	21.61	0	296.00
Irrigated Soil Class3	21721	1.79	7.79	0	163.80
Irrigated Soil Class4	21721	1.41	7.18	0	199.21
DemeanElev	21721	.0014	49.82	-86.81	345.23
DemeanPrecip	21721	.0024	1.91	-2.88	11.28
DemeanTemp	21721	.0018	0.46	-1.42	1.33
DemeanElev*Acres	21721	103.70	4203.06	-21015.02	89633.59
DemeanPrecip*Acres	21721	-3.61	157.71	-766.09	3127.31
DemeanTemp*Acres	21721	-4.23	31.98	-403.60	242.59

4.5 Discussion of Expected Sign and Magnitude of Coefficients

The expectation is that the irrigated and unirrigated soil class variables should have the largest explanatory power among the model variables, since land rents were attributed to tax lots on the basis of the number of acres of irrigated and unirrigated soils of each class in the tax lot. Irrigated soils should have higher coefficients than non-irrigated soils reflecting the higher value of irrigated land, and higher quality soils should have higher coefficients than lower quality soils, reflecting the productivity differential between those soils. The model should also be able to pick up on the variation in land rents between agricultural zones and attribute those differences to variations in elevation, temperature and precipitation. It is expected that the coefficient on demeaned elevation should be negative, since LCC and irrigation variables are unlikely to capture all of the advantages of valley bottom lands, while the coefficients on demeaned precipitation and temperature should be positive. A marginal increase in growing season precipitation should improve growing conditions and increase yield, which raises profits and should be positively reflected in the rental value of the land. Similarly, a marginal increase in average minimum growing season temperature should correspond to better growing conditions and possibly indicate reduced risk from frost damage. Hence, the coefficient on demeaned temperature should be positive as well. The interaction terms are expected to reflect the differential impact of climatic and elevation variables on parcels of different size. Without these terms, the model would return effects for an average sized parcel. It seems reasonable to expect that above average elevation would negatively affect every additional acre in a parcel, so the coefficient on the interaction for demeaned elevation and acres should be negative. The literature has reported that the value of irrigation rights demonstrates decreasing returns to scale, declining in value for larger farms (Butsic and Netusil, 2007; Yoo et al. 2013). Precipitation should exhibit similar behavior, and the sign on the interaction term between demeaned precipitation and acres should be negative. The interaction of demeaned temperature and acres should be positive. Every additional acre in a parcel should benefit from better growing conditions and reflect positively on total parcel value.

4.6 Hedonic Analysis – Estimation Results

The estimated hedonic model for land rents is presented in Table 6. There are a total of 16 explanatory variables and all are significant at the 1% level or better. This model explains 93% of the variation in the data. It is apparent that agricultural rents increase with better soil quality. The soil coefficients are interpreted as the increase in parcel value from the addition of an acre of soil of given quality. Average rents range from about $105 per acre per year on unirrigated class 1 soils to $20 per acre per year for class 6 and 7 soils. The actual value for Class 6 and 7 soils are even lower, since those soils are generally found on more marginal land, at higher elevations and lower temperatures. Taking the average elevation, precipitation and temperature for fields with such soil type into account, an acre of class 6 soil is worth approximately $15, while an acre of class 7 soils is valued at $5.

The average value of water rights is obtained from the difference in rent value between an irrigated and an unirrigated acre of the same soil class. Table 7 shows the value of water rights by soil class. Water rights have a higher value on class 1 and 2 soils (about $39 per acre per year) than on class 3 and 4 soils ($18-22 per acre per year). This seems reasonable, given that a water right should generate a greater profit on more productive soils. Water values are based on an average irrigation requirement in the Willamette Valley of 1.7[2] acre feet (Cuenca 1992) and were estimated to be about $23 per acre foot for class 1 and 2 soils and $13 and $10 for class 3 and 4 soils respectively.

The effects on land value from variations in average growing season minimum temperature, elevation, and precipitation are shown in Table 7. Those coefficients indicate the change in the value of a field resulting from a one unit change in the level of the climate or elevation variable for an average sized field. This is somewhat difficult to interpret, particularly because of the additional interactions that account for how changes in climate and elevation affect fields of different sizes. Table 7 shows the values of those

[2]The average irrigation requirement was derived from an area weighted average of the irrigated shares of the top ten crops in the Willamette Valley: berries, corn, fruits and nuts, grass seed, greens/herbs, hay, nursery crops, vegetables, clover, wheat, grain.

changes calculated for the sample average sized parcel of 54.3 acres. A marginally higher elevation corresponds to a decline in land value of $0.04 per acre. The value of an inch of higher precipitation is $1.37 per acre, or $16.44 per acre foot. A one degree C increase in average growing season minimum temperature corresponds to greater land value of $26.6/acre.

Table 6: Hedonic model for land rents. The dependent variable is parcel value, in dollars.

Variables	Coefficient Estimates	Standard Error	T-statistic	P-value
Soil Class1	104.72	1.39	75.54	0.000
Soil Class2	95.59	0.37	260.77	0.000
Soil Class3	69.90	0.45	156.98	0.000
Soil Class4	66.64	0.46	145.54	0.000
Soil Class6	20.52	0.86	23.94	0.000
Soil Class7	19.95	2.86	6.98	0.000
Irrigated Soil Class1	143.65	1.15	125.01	0.000
Irrigated Soil Class2	134.70	0.40	335.68	0.000
Irrigated Soil Class3	87.73	1.06	83.08	0.000
Irrigated Soil Class4	88.75	1.16	76.74	0.000
DemeanElev	-1.06	0.39	-2.71	0.007
DemeanPrecip	98.46	9.16	10.75	0.000
DemeanTemp	351.59	30.73	11.44	0.000
DemeanElev*Acres	-0.020	.0053	-3.65	0.000
DemeanPrecip*Acres	-0.44	0.12	-3.57	0.000
DemeanTemp*Acres	20.10	0.51	39.70	0.000
Constant	65.48	11.62	5.63	0.000

Note: R2 = 0.93, Sample size = 21,721

Table 7: Irrigation water right values, and deviations from climate and elevation means for average parcel

Value of a water right by soil class $/acre/year		**Value of water per acre foot, ($/year)** [a]
Irrigated Soil Class1	38.93	22.9
Irrigated Soil Class2	39.11	23.0
Irrigated Soil Class3	17.83	10.49
Irrigated Soil Class4	22.11	13.01
Marginal value of a unit deviation from average, for average sized field		
Elevation	-0.04 ($/meter/acre)	
Growing seas. Precip	1.37 ($/acre inch)	
Growing seas. min. temp.	26.6 ($/degree C/acre)	

[a] Based on average irrigation requirement of 1.7 acre feet

V. Modeling Irrigation Decisions

Section 3.6 alluded to the problem of unused water rights in the Willamette Valley, why would half of the existing water rights not be used in a given year? This aspect of agricultural water use makes the work of water resource planners more difficult as they try to separate “paper water” quantities (legal maximums) from actual water used, in order to make informed decisions about water policy. Some reasons for this pattern of water use may relate to the circumstances facing individual farmers that change from year to year, leading to fluctuation in the use of water rights. There may also be longer term trends affecting the irrigation decision, for example an increase in the price of energy and fertilizers over time may have made it unprofitable to irrigate some land that at one point in the past was irrigated under different market conditions. Additionally, climatic variables may play a role, where availability of precipitation may substitute for irrigation for some farmers. These may all be plausible explanations, but without observations of field level irrigation decisions that relate to use of water rights, and data on land quality conditions constraining the farmer managing that field, it is difficult to say anything more specific.

To yield greater insight into farmers' irrigation decisions, survey data were collected in the fall of 2012 about their irrigation and crop choice decisions farmers made on specific fields over the past six years. Results of the survey were combined with spatial data on climate and land quality variables and a model of a farmer's irrigation decision was developed using this data. This section provides a theoretical framework for a model of a farmer's irrigation decision in sub section 5.1. Sub section 5.2 outlines sample selection procedure for the survey of irrigators. Irrigation survey design is discussed in sub section 5.3. Survey results are discussed in sub section 5.4. Section 5.5 is a discussion of variable selection for model of irrigation decision. Irrigation model specification is outlined in section 5.6, evaluation of model fit is presented in section 5.7, and estimation results in sub section 5.8

5.1 Theoretical Framework for Irrigation Decision Model

Consider a farmer *n* who faces a decision of whether or not to irrigate. He gets some utility from each alternative, represented as U_{nj}, with j=1,2 for the binary decision. The farmer will chose to irrigate if utility with irrigation is greater than utility without, that is if $U_{ni} > U_{nj}$ where i≠j. While we do not know the farmer's preferences, we can observe some attributes which affect the choice between the two alternatives. V_{nj} is the observed component of the farmer's utility function and represents observable variables like soil quality, climate, proximity to markets and drainage characteristics of the land among others. These observable land characteristics pertain to the geographic location and productivity of the land and can directly influence the irrigation decision. Additionally there are many unobservable attributes of the farmer and his land which also affect the irrigation decision, denoted as ε_{nj}.

The farmer's utility U_{nj} can correspondingly be decomposed into the observed component V_{nj} and unobserved component ε_{nj}

$$U_{nj} = V_{nj} + \varepsilon_{nj}$$

Observed component of utility V_{nj} can be considered as the deterministic component of the farmer's decision about irrigation and ε_{nj} is the stochastic component that is treated as a random variable. The joint density of the random vector $\varepsilon_n = \{ \varepsilon_{n1,} \varepsilon_{n2}\}$ can be denoted as $f(\varepsilon_n)$. By making assumptions about the distribution of the stochastic component of the utility function and utilizing the joint density function, it is possible to evaluate statements about the probability of irrigation which can be written as:

$$P_{ni} = \mathrm{P}(U_{ni} > U_{nj} \ \forall \ i \neq j)$$

$$= \mathrm{P}(V_{ni} + \varepsilon_{ni} > V_{nj} + \varepsilon_{nj} \ \forall \ i \neq j)$$

$$= \mathrm{P}(V_{ni} - V_{nj} > \varepsilon_{nj} - \varepsilon_{ni} \ \forall \ i \neq j)$$

We assume that the unobservable term has a Type I extreme value distribution, which is a member of the generalized extreme value distribution family that is used to model smallest and largest outcomes for sets of independently and identically distributed random variables. This leads to a logistic distribution for the difference in the unobservable terms (Greene, W.H. 2011)**.** The result suggests the use of a binomial logit model which relates the probability of irrigation to the observable component of utility. If we specify the known component of utility V_{nj} as a linear function of observable characteristics of the farmer's land

$$V_{nj} = X_{nj}\beta$$

then the probability of irrigation for the n^{th} farmer is

$P_{ni} = \frac{e^{X_{ni}\beta}}{\sum_j e^{X_{nj}\beta}}$ which is the cumulative distribution function of the logistic distribution.

5.2 Survey Sample Selection

To better account for irrigation water use, a sample of Willamette Valley irrigators were surveyed in the fall of 2012 about their irrigation and crop choice decisions over the past six years. While it would have been preferable to collect a longer time series of data for model development, resources for data collection were limited. Importantly, the survey captured farmer's irrigation decisions prior to the effects of the 2008 economic downturn, which are known to have affected crop prices, land allocations, and irrigation decisions. The six year time frame for the survey thus can be used to make inferences about more general irrigation dynamics outside of the period of recession. The survey had a unique design in that farmers were asked to identify their irrigated fields on a map, so that their responses could be matched to land quality and climate data. Integration of survey responses with spatial data allowed for development of an irrigation decision model to account for the intermittent use of water rights by irrigators.

Irrigator survey sample selection and data collection were carried by the Portland, OR office of USDA National Agricultural Statistics Service. The population of interest for the survey consisted of known irrigators with ten or more irrigated acres, operating within the boundaries of the Willamette Valley. Irrigators were drawn from postal zip codes within the Willamette Valley, stratified by county and by the number of irrigated acres in the operation, to ensure a representative sample of irrigated farms. Farm level irrigated acreage indicated in the 2007 Census of Agriculture and available to the USDA staff was used as the basis for selecting farmers for the survey. Sample size was set at 530 farmers, in part due to costs of data collection but also from consideration that each farmer will likely have multiple irrigated fields that he/she would be able to provide data for. The amount of agricultural land surveyed in each county is summarized in Table 8.

Table 8: Acres of Survey Fields by County.

County	Survey Field Acres	Percent of Total
Benton	2863.8	8.21
Clackamas	2559.2	7.33
Lane	1693.7	4.85
Linn	3441.5	9.86
Marion	11587.3	33.21
Multnomah	598.8	1.72
Polk	3894.0	11.16
Washington	4136.2	11.85
Yamhill	4119.9	11.81
Total	34894.424	100.00

5.3 Irrigation Survey Design

The irrigation survey was designed to obtain field level, panel data on crop and irrigation choice from farm operators and connect that information to a spatial data set containing climate, and land quality information for the same fields. To achieve this, maps of agricultural tax lots covering the entire Willamette Valley were prepared for the USDA survey enumerators to take with them when surveying farmers. It was not possible to determine specific locations to map ahead of time due to privacy concerns with the USDA, so mapping the entire extent of the agricultural area in the Willamette Valley was required. Tax lots were identified with a unique id and mapped with streams and roads over base orthographic aerial imagery from 2012 (USDA Geospatial Gateway) to aid in identifying the correct fields. Two hundred black and white 35 by 35 inch maps, each covering a 7x7 mile square of the Willamette Valley at a scale of 1:13000 were printed for survey data collection.

Farmers were asked if they had any irrigated fields. If the answer was none, the interview was concluded. Otherwise, a farmer would mark his field boundaries on a tax lot map for that area, modifying polygon boundaries if necessary, and provide information on the crops planted and irrigation decisions made on up to three of his fields for each year between 2007 and 2012. To ensure greater clarity, farmers were asked to indicate whether a field was irrigated entirely, partially or not at all. This was done to reduce potential bias from combining full irrigation and partial irrigation responses together, since partial irrigation does not have a clear interpretation. Data was collected from up to three fields per farmer.

Following completion of the survey, the spatial database of tax lots used to create maps for enumerators was cross referenced with the maps used by the farmers to identify field boundaries and edited to reflect the changes farmers made to reflect their field boundaries. A new spatial dataset was created from the tax lot database with only the fields that were identified in the survey and joined with the survey results via the common tax lot id. This spatial data set of farmers' fields made it possible to derive other variables relevant to irrigation, describing land quality, climate and geographic attributes of a field.

5.4 Irrigation Survey Data

Five hundred and thirty irrigators from across the Willamette Valley were sampled about their irrigation and cropping decisions, with 421 responses and 339 valid responses where a farmer was able to provide data on at least 1 irrigated field. Respondents provided information about 747 fields in total, with 717 fields that had complete information about crop and irrigation choices over all 6 years. This corresponds to 4409 field year observations. The fields surveyed sum to 35, 016 acres of agricultural land, with an average field size of 46.9 acres. Table 9 provides additional information about the average number of fields owned, average number of irrigated fields and the frequency with which fields with irrigation water rights are actually irrigated.

Table 9: Field ownership and irrigation practices (standard deviations are included in parentheses)

Farm and Irrigation Overview		
Average number of fields owned	10.36	(17.47)
Average number of irrigated fields	7.84	(14.9)
Among Irrigated Fields:		
Fields irrigated 0-1 years out of 6	7.7%	(21.5)
Fields irrigated 2-5 years out of 6	22.5%	(36.4)
Fields irrigated 6 years out of 6	67.9%	(43.5)
Not specified by Operator	1.2%	

Among the surveyed fields, 65.9% of the acreage was fully irrigated, 13% partially irrigated and 21.1% not irrigated. These percentages are broken down by crop categories in Table 10 to illustrate the extent to which certain crops are grown with and without irrigation. Summing percentages across rows yields a crop’s share of total acreage surveyed, while summing percentages by columns results in shares of land that was irrigated, partially irrigated or not irrigated at all. Grass seed, hay, and wheat together make up 43.8% of survey area and were observed to have substantial acreage that was both irrigated and not irrigated. Corn, nursery crops, vegetables and berries on the other hand were almost always irrigated. It can be seen that while many of the same crops are grown with and without irrigation, the patterns of land allocation on irrigated and non-irrigated fields are quite different. Table 11 breaks down crop area by percent of the acreage irrigated, partially irrigated and not irrigated.

Table 10: Crop area by irrigation type as percentage of total surveyed farm area

Crop	Irrigated, % of Total Acres	Partially Irrigated, % of Total Acres	Non irrigated, % of Total Acres	% of Total Acres
Grass Seed	16.33	1.31	9.86	27.50
Nursery	9.23	2.91	0.39	12.52
Corn	8.73	0.36	0.01	9.10
Vegetables/Greens	10.5	1.66	0.32	12.48
Berries	6.13	0.97	0.15	7.25
Hay	6.10	1.79	1.80	9.69
Wheat	1.23	0.21	5.16	6.60
Fruits and Nuts	4.44	0.89	0.85	6.18
Clover	0.73	0.08	0.62	1.43
Grains	0.54	0.13	0.49	1.17
Fallow	0.00	0.00	1.16	1.16
Christmas Trees	0.28	0.25	0.21	0.74
Other	1.68	2.46	0.04	4.19
Percent of Total	**65.92**	**13.02**	**21.06**	**100.00**

Table 11: Percentages of crop acres by irrigation type

Crop	Percent Crop Irrigated	Percent Crop Partially Irrigated	Percent Crop Not Irrigated
Grass Seed/Grass	59.39	4.77	35.84
Nursery/Horticulture	73.7	23.21	3.09
Corn	95.92	3.94	0.14
Vegetables/Greens	84.16	13.25	2.59
Berries	84.59	13.38	2.03
Hay	62.94	18.51	18.55
Wheat	18.61	3.15	78.24
Fruits/Nuts	71.9	14.31	13.8
Clover/Clover Seed	50.91	5.88	43.21
Grains	46.57	11.62	41.81
Christmas trees	37.35	33.52	29.13
Other	38.63	60.30	1.07

5.5 Irrigation Model Variable Selection

The irrigation decision, as described above, depends on many factors that affect a farmer's profits. Some of these factors may be idiosyncratic, like whether the irrigation equipment is already on the field or not, the amount of additional work required to manage the irrigation system and family habits and traditions in farming. These variables are difficult to observe. Other important factors pertain to measures of climate and land quality, and it is possible to observe them. Together these factors determine whether the additional profits from irrigation justify the energy and labor costs required to manage an irrigation system. In this section, observable characteristics that are important to the irrigation decision and are included in the irrigation decision model are discussed in terms of their effect on the probability of a field being irrigated. These variables are derived for the spatial data set of fields identified in the irrigation survey.

The variables included in the model can be grouped in four general categories: climatic, land quality, geographic and water right type. The climatic variables of interest are deviations in monthly summer precipitation and temperature from 30 year average monthly precipitation and temperature. Land quality variables span measures of elevation, soil quality, drainage characteristics and field size. Geographic variables describe the location of a field with relation to agricultural markets in big cities, exclusive farm use land zoning and the floodplain of the Willamette River. Water right variables include an indicator of a water right type, whether it is a ground or surface water right, and the depth to groundwater.

Both temperature and precipitation have been shown to be important in predicting irrigation adoption (Negri et al. 2005). In conditions of increasing temperature and decreasing precipitation, crop demand for water increases as the amount of available water decreases, increasing demand for irrigation water. Correspondingly temperature should be positively correlated and precipitation negatively correlated with probability of irrigation. Due to severe collinearity however, only precipitation variables were included in the model. Precipitation is specified as monthly deviation from 30 year average conditions for summer months (monthly precipitation – 30 year average monthly precipitation)

Elevation provides an indirect measure of land quality, reflecting some factors not captured with good resolution by LCC, such as slope. Land at higher elevation can be of lower quality and less productive relative to valley bottom lands. One reason for that is due to alluvial deposits left by streams that primarily affect valley bottom soils and generally make them more productive. Additionally, transport and pumping costs for water may increase with elevation, and as a result, elevation should have a negative effect on the probability of irrigation. An interaction term between elevation and precipitation is also included, since precipitation and elevation are closely linked, and may have nonlinear effects. An increase in both elevation and precipitation should have a negative effect on the probability of irrigation for reasons discussed above. The precipitation variable is the sum of 30 year average precipitation for April, May and June, in inches.

Measures of soil quality and soil attributes that influence drainage directly affect land productivity, suitability of land for irrigation and consequently the irrigation decision. Better quality soils generate higher profits and irrigation on such land is more likely to justify the additional electricity and management costs. Therefore good quality soils should be positively correlated with the probability of irrigation. Soil quality is indicated with soil class dummy variables for the soil class that makes up the largest area share of a field. Poor drainage should be negatively correlated with probability of irrigation, since irrigation of such land likely requires additional management effort. Higher soil water holding capacity should likewise negatively affect the probability of irrigation. As soil water storage increases, potentially as a result of higher organic matter content, the need for irrigation decreases, allowing the water stored from spring rains to meet crop water demand. Field size is included as a measure for economies of scale, which represent changes to cost of irrigation resulting from changes in labor and capital costs involved in irrigating a larger field. As a result of higher management costs, larger fields may be less likely to be irrigated (Negri and Brooks 1990).

Among geographic variables, distance from the Willamette River provides a measure for the effect of floodplain deposits on land quality and of water transport delivery costs for fields that are irrigated from the Willamette River. Increasing distance from the river is likely to negatively affect land quality, increase irrigation costs and should hence be negatively correlated with probability of irrigation. A measure of proximity to cities should also concern the irrigation decision, because cities can provide markets for agricultural products. Increasing distance from urban centers may have a negative effect on the probability of irrigation due to higher transport costs. It is also important to differentiate land that may belong to part time farmers from that used by land owners for whom farming is the main occupation, since they are more likely to invest resources into irrigation according to previous research on irrigation adoption (Schuck et al. 2005). The presence of an agricultural field within the Exclusive Farm Use (EFU) zoning may be an indicator that the land owner is not a part-time or “hobby farmer,” since land uses other than farming are excluded on EFU land. EFU zoning should be positively correlated with probability of irrigation.

For variables related to water rights, a dummy variable is included to indicate that a field is irrigated by groundwater and an interaction term is created for that dummy term with a variable representing depth to groundwater. It is unclear whether irrigation type will affect the probability of irrigation. The interaction term however should have a negative effect on the probability of irrigation. As depth to groundwater increases, the cost of pumping groundwater should increase and decrease the probability of irrigation. Table 12 presents the variables used in the irrigation decision model. Table 13 shows summary statistics for the variables.

Table 12: Irrigation decision model variables

Variable	Description
June Precip. Deviation	June deviation in precipitation from long-run average
July Precip Deviation	July deviation in precipitation from long-run average
August Precip Deviation	August deviation in precipitation from long-run average
Elevation	Average field elevation (10 meter resolution)
Elevation*SpringPrecip.	Interaction term for elevation and spring precipitation (April-June)
EFU Zoning	Dummy variable for field location in EFU zone
Field Size	Field size in acres
GW Right	Dummy variable for a groundwater right
Percent Poor Drainage	Percent of field classified as being poor drainage
GW Right*GW Depth	Interaction term for groundwater depth and groundwater right
Water Holding Capacity	Average soil water holding capacity for field (cm)
Willamette River Distance	Distance from field to Willamette River (km)
Big City Distance	Distance from field to the nearest city with over 50,000 population
Majority LCC1	Dummy variable for majority soil class1
Majority LCC2	Dummy variable for majority soil class2
Majority LCC3	Dummy variable for majority soil class3
Majority LCC4	Dummy variable for majority soil class4
Majority LCC5 and LCC6	Dummy variable for majority soil class5 or 6

The climate data were obtained from the PRISM Climate Group of Oregon State University. Soil classes and average soil water holding capacity were derived from the USDA SSURGO soils database. Groundwater levels were obtained from Roy Haggerty, Professor of Environmental Geology at Oregon State University. Elevation data was obtained from the USDA Geo Spatial Gateway data clearinghouse. Oregon Water Resourced Department water rights database was used to calculate extent and type (surface or groundwater) of irrigation on a field. Distance from the centroid of a field to the Willamette River and the nearest major city of over 50,000 was calculated using the streams and cities layers obtained from Oregon GIS Clearinghouse.

Table 13: Summary of irrigation regression variables

Variable	Obs	Mean	Std. Dev.	Min	Max
June Precip. Deviation	4409	-0.061	1.022	-2.12	4.57
July Precip Deviation	4409	-0.088	0.35	-0.79	1.66
August Precip Deviation	4409	-0.11	0.48	-1.022	1.95
Elevation	4409	87.099	61.045	4.048	455.59
Elevation*SpringPrecip.	4409	739.81	755.48	30.29	6020.21
EFU Zoning	4409	0.87	0.33	0	1
Field Size	4409	45.85	53.70	0.21	544.68
GW Right	4409	0.45	0.49	0	1
Percent Poor Drainage	4409	16.043	23.56	0	100
GW Right*GW Depth	4409	6.43	16.49	0	179.82
Water Holding Capacity	4385	9.46	1.28	3.28	19.96
Willamette River Distance	4409	10.78	8.11	0	54.67
Big City Distance	4409	23.20	9.56	2.31	54.79
Majority LCC1	4409	0.084	0.27	0	1
Majority LCC2	4409	0.64	0.47	0	1
Majority LCC3	4409	0.18	0.38	0	1
Majority LCC4	4409	0.062	0.24	0	1
Majority LCC5 and LCC6	4409	0.020	0.14	0	1

5.6 Irrigation Decision Model Specification

While it is apparent from the survey data that fields are irrigated both partially and in their entirety, only fields that are entirely irrigated are modeled. This leads to an under estimate of the amount of irrigation that takes place. Partial irrigation is not explicitly modeled because it is not clear what it represents, and it was indicated as an option on the farmer irrigation survey to separate instances of complete and partial irrigation. Partial irrigation may involve irrigation of a few acres of exceptional land that are part of a bigger field, or irrigation of only one crop on a field with multiple crops, or something else depending on how a farmer may interpret it. As such, it is not a useful or predictable measure for water use. Correspondingly, complete irrigation on fields was the outcome of interest that was modeled with a binary logit model.

Other model specifications and estimators were considered prior to selecting the logit, specifically the fixed and random effects logit models as well as a linear probability model. A fixed effects model was found inappropriate for this application because permanent characteristics of fields representing land quality and geographic location could not be included in the model. A random effects model consistently over predicted the probability of irrigation, not returning the mean probability of irrigation observed in the data. Possibly that was a result of the model treating each field as an individual decision unit and assigning field level random effects when in reality multiple fields could be owned by one farmer. An attempt to create an irrigated field count model by averaging field attributes by field owner and applying the random effects model to this data yielded a similarly high probability of irrigation. It is unclear why the random effects model did not return the mean probability of irrigation. A linear probability model was not used because it was problematic to ensure that probabilities would not exceed or be less than one. The logit model is estimated as follows, first calculating the log of the odds ratio, then exponentiating it to find the probability of irrigation:

$$Ln(P_{IRR}/(1-P_{IRR})) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_{17} X_{17}$$

$$P_{IRR} = \frac{1}{1+e^{-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_{16} X_{16})}}$$

5.7 Evaluation of model fit

A modified "percent correctly predicted" statistic was used to assess model fit. The standard percent correctly predicted statistic where an outcome is indicated based on a 50% probability cut off is not a good measure of model fit for a stochastic dependent variable. If the probability of irrigation for a field is 0.6, that means the field on average will be irrigated 6 out of 10 years, not that it will be irrigated every year because the probability is greater than 0.5. Taking this into account, a modified approach was used to assess model fit. Following estimation of irrigation probabilities for fields, a random uniform variable was drawn for each field on the interval from 0 to 1. If the uniform variable was less than the probability of irrigation, the field was marked irrigated. If it was greater, the field was marked not irrigated. This approach incorporates the stochastic aspect of the irrigation decision into the assessment of fit.

5.8 Estimation Results

The average probability of irrigation was observed to be 0.69 for the survey sample. Estimated coefficients for the irrigation logit model are presented in Table 14 and marginal effects at the means for all variables in Table 15. All coefficient except August and June deviation in precipitation were significant at below the 5% level. The modified procedure for identifying the percent of fields correctly predicted shows that the model correctly predicted 71% of irrigated fields and 36% of unirrigated fields, for an overall 60% correctly predicted (Table 16).

Coefficients for the precipitation variables representing monthly deviation from the average were negative as expected. Greater precipitation reduces the need for irrigation. The fact that only the coefficients for June and July were significant is reasonable, given that by August the irrigation decision should have already been made. The marginal effect of an additional inch of precipitation above the long run average in June is a 2%

reduction in the probability of irrigation while an extra inch in July corresponds to an 8.5% reduction in the probability of irrigation. The coefficient on elevation was negative, which matched our expectations but the interaction term between elevation and precipitation was positive. It is counter intuitive that the probability of irrigation would increase with increasing elevation and precipitation, although this result may be a product of outliers in the data. The effect of a marginal increase in elevation was a 0.20% percent decline in the probability of irrigation, or approximately a 20% decrease for a 100 meter increase from the mean elevation of 87 meters.

Field location within the EFU zone was positively correlated with the probability of irrigation, with a 9% increase in the probability of irrigation for a field on EFU zoned land. The coefficient on field size was negative. A one acre increase in field size above the mean of 45.9 acres results in a 0.08% decline in probability of irrigation. The coefficient on groundwater irrigation was positive, with a corresponding 7% increase in the probability of irrigation for a field with a primary groundwater right. A negative coefficient was observed for the interaction between groundwater irrigation and depth to groundwater, which describes the effect of groundwater depth, and by direct association increase in pumping costs, on fields with groundwater rights. For a marginal increase of a meter in depth to groundwater, the probability of irrigation declined by 0.2 %.

Both the share of a field with poor drainage and a field's soil water holding capacity, were both negatively correlated with the probability of irrigation. An additional percentage of poorly drained soils on a field, increasing from an average of 16%, reduces the probability of irrigation by 0.18%, while an additional centimeter of soil water holding capacity, above the mean of 9.4 cm, decreases probability of irrigation by 4.6%

Distance from the Willamette River and from major cities in the valley also had a negative effect on irrigation. An additional km from the river beyond the mean distance of 10.8 km corresponded to a decline of 0.55% in the probability of irrigation while an additional km from a major city above the average distance of 23.2 km reduced the probability of irrigation by 0.18%.

Soil variables, with class 5 and 6 soils excluded, were all positively correlated with probability of irrigation. Only class 4 soils appear to be significantly different than the other three however. 17%, 23% and 17% increases in probability of irrigation for class 1, 2 and 3 soils appear to be indistinguishable based on significance tests.

Table 14: Irrigation decision regression estimates

Variables	**Coefficient Estimates**	**Standard Error**	**P-Value**
June Precip. Deviation	-0.0943	0.0510	0.065
July Precip Deviation	-0.4134	0.1485	0.005
August Precip Deviation	-0.1584	0.1204	0.188
Elevation	-0.0098	0.0026	0.000
Elevation*SpringPrecip.	0.0008	0.0002	0.000
EFU Zoning	0.4307	0.1092	0.000
Field Size	-0.0038	0.0006	0.000
GW Right	0.3311	0.0874	0.000
Percent Poor Drainage	-0.0084	0.0018	0.000
GW Right*GW Depth	-0.0094	0.0024	0.000
Water Holding Capacity	-0.2190	0.0322	0.000
Willamette River Distance	-0.0261	0.0054	0.000
Big City Distance	-0.0087	0.0042	0.037
Majority LCC1	0.8397	0.2701	0.002
Majority LCC2	1.0799	0.2475	0.000
Majority LCC3	0.8206	0.2514	0.001
Majority LCC4	1.4981	0.2797	0.000
Constant term	2.42	0.4076	0.000

Table 15: Marginal effects at variable means

Variables	dy/dx	Standard Error	P-Value
June Precip. Deviation	-0.0197	0.0107	0.064
July Precip Deviation	-0.0863	0.0310	0.005
August Precip Deviation	-0.0331	0.0251	0.188
Elevation	-0.0020	0.0005	0.000
Elevation*SpringPrecip.	0.0002	4E-5	0.000
EFU Zoning	0.0899	0.0228	0.001
Field Size	-0.0008	0.0001	0.000
GW Right	0.0691	0.0182	0.000
Percent Poor Drainage	-0.0018	0.0004	0.000
GW Right*GW Depth	-0.0020	0.0005	0.000
Water Holding Capacity	-0.0457	0.0067	0.000
Willamette River Distance	-0.0055	0.0011	0.000
Big City Distance	-0.0018	0.0009	0.036
Majority LCC1	0.1754	0.0565	0.002
Majority LCC2	0.2255	0.0518	0.000
Majority LCC3	0.1714	0.0526	0.001
Majority LCC4	0.3129	0.0584	0.000

Table 16: Percent of correctly predicted fields

	Predicted Irrigated	Predicted Non Irrigated	Total
Observed Irrigated	2,178	879	71.2%
Observed Non Irrigated	861	491	36.3%
Overall Correctly Predicted			60.5%

VI. Discussion

6.1 Hedonic Model

Results of the hedonic price decomposition of farmland value indicate that the novel approach to Ricardian farmland valuation that was developed in this study by using land rents, tax lots and spatial data on land quality, irrigation and climatic variables was successful. The hedonic model identified statistically significant effects of elevation, precipitation and temperature on land value based on variations in land rents across agricultural zones and estimated average values of irrigated and unirrigated land by soil class from which the value of water was calculated.

Three aspects of this analysis are important to discuss. One relates to the insights the hedonic model provides about the present level of water scarcity in the Willamette Valley. How do the marginal values of water observed in the Willamette Valley compare to values in other part of Oregon and the U.S West in general? What do the observed values of water imply about the importance of irrigation rights to the Willamette Valley agriculture? The second concerns internal consistency of model, specifically, what does a comparison of the values of water from water rights and water from precipitation say about the accuracy of the model? The third pertains to understanding the effects of future changes in climate and water availability on farmland value. What can this model reveal about the economic effects of those changes? What is the limit on the predictive capability of the model?

The irrigation water values that were observed, ranging from $13 per acre foot on class 4 soils to $23 per acre foot on class 1 and 2 soils, are similar but somewhat lower than values observed in other studies of irrigation water value in Oregon, reviewed here in 2011 dollars. Jaeger (2004) reports irrigation water values ranging from $20 - $67 per acre foot across the same range of soil quality in the Klamath Basin, a more water scarce region compared to the Willamette Valley. Faux and Perry (1999) found a range of water values similar to the Klamath Basin for irrigation in Malheur County in South Eastern Oregon which, like the Klamath Basin, is a water scarce region. They observed water values from $14 per acre foot on class 4 soils to $59 per acre foot on class 1 soils. The values of water observed for the Willamette Valley are lower than in the arid parts of Oregon, and also compared to the average in the Western US, which was reported to be $38 per acre foot (adjusted to 2011 dollars) by Grafton et al. (2011) in a summary of 239 agriculture to agriculture leases from 1987 to 2008. It seems reasonable that as aridity increases, ,the value of water increases. Given that Willamette Valley receives considerably more precipitation than Eastern Oregon and the Western US in general, our observed lower value of irrigation water is not surprising. The estimated value of irrigation water is consistent with the intermittent patterns of irrigation water right use observed in the Willamette Valley, and may reflects the availability of sufficient precipitation to produce many crops without irrigation. Only Butsic and Netusil (2007) found values similar to those for the Willamette Valley. Their study of water values in Douglas County, also in western Oregon and just south of the Willamette Valley, estimated irrigation water was worth about $20 per acre.

Comparing the estimated value of water from a water right to the value of a marginal change in precipitation may provide a "check" on the validity or consistency of the model estimation. The value of rainfall over the growing season was found to be $1.37 for a marginal acre-inch of precipitation on an average sized field of 54.3 acres. Converted to acre feet, that is $16.44 per acre foot. The value of rainfall is strikingly close to the value of irrigation water. This result is consistent with economic theory in that rainfall and irrigation water may be viewed as substitutes, and that as a result, water should be similarly valued whether it comes from a water right or as rain. It is also not surprising however that the estimated value of rainfall is lower than that of irrigation water, given that rainfall cannot be controlled.

Another variable that may reflect on model validity is the average growing season minimum temperature. The coefficient on this term seems quite high ($26.5/acre/year), considering that a one degree increase in average minimum temperature involves a one degree warming for each day of the growing season. This is a lot of additional heat for plants over the course of a growing season. Previous studies have reported both positive and negative effects of increasing temperature on agricultural land values, with those effects varying seasonally(Mendelsohn 2003, 2007), suggesting a more complex relationship between temperature and land value. In this study, limited variability in average growing season minimum temperature, which spans a range of only two degrees across the Willamette Valley may have biased the temperature coefficient.

This leads to a mixed conclusion. The similarity of precipitation and irrigation water values suggests that despite not being able to include quadratic terms to reflect the nonlinear relationship of temperature and precipitation variables, the linear specification of the model appears to have been sufficient to represent the relationship between those climatic variables and land value in the Willamette Valley. The accuracy of the coefficient on the average minimum temperature variable is questionable however, and there is no other consistency check within the model that could be used as a reference for the accuracy of the temperature variable coefficient.

The hedonic model provides a valuable tool for yielding insights into some of the economic effects of changing water availability on the agricultural economy of the Willamette Basin. An important use of the model may be in evaluating the effect of water rights loss on agricultural land. Climate change predictions for the Willamette Basin raise expectations of drier, warmer summers and lower stream flows which may lead to increased regulation of water rights for junior water rights holders, and reduced access to irrigation. The hedonic price schedule can be used to estimate expected changes in land values for the parcels most vulnerable to future changes in stream flows. This model could also be used to evaluate efficiency gains resulting from changes to how water rights are regulated. For example, there are land owners who have high quality agricultural land but junior water rights and those that have senior water rights, but low quality land. If these land owners were allowed to negotiate short term water lease agreements that would make irrigation water available to the more productive land, both could be left better off. The model is less suitable for assessing effects of large deviations from present climatic conditions on farmland value. One reason for this is that the current model was estimated from data with limited cross-sectional variability in climatic conditions within the Willamette Valley. Another reason is that this is a partial equilibrium analysis that is based on the assumption of constant input and output prices.

In considering large deviations from current climatic conditions, land values outside of the Willamette Valley, as well as crop prices and production in other regions, would also be affected and could change the equilibrium land values in unpredictable ways, limiting the reliability of such analysis.

6.2 Irrigation Model

Looking at the marginal effects of changes in the levels of the model variables on probability of irrigation yields some interesting insights. Three results stand out: a) the low magnitude of the effect of precipitation variables on irrigation, b) the positive effect of groundwater irrigation, and c) the lack of an ordered soil quality effect where probability of irrigation increases with soil quality. Both intuition and anecdotal conversations with farmers suggest that early summer precipitation is an important variable in the farmer's irrigation decision. Given plentiful early season precipitation, irrigation may not be required for certain crops. It was surprising then to see that a marginal one inch increases in June and July precipitation above the long run average yielded increases of only 2% and 8% in the probability of irrigation. One possible explanation for the small magnitude of the precipitation effects is that the pattern of precipitation over the surveyed years involved wetter than average springs and drier than average summers. Over the survey period, precipitation in April and May was 5% greater than the 30 year average, while June precipitation was 4% lower and July precipitation 16% lower. It is possible that we did not capture enough variability in summer precipitation within the years surveyed to correctly estimate the magnitude of farmers' response to wetter than average summer conditions.

Relevant to precipitation are the soil drainage and water holding capacity characteristics, influenced by the amount of clay, silt and organic matter in the soil. The marginal effects for increases in levels of these variables suggest a rather small impact on the irrigation decision, but in keeping with previous observations that irrigation is less likely on soils with extreme characteristics, like high clay or sand content (Negri et al. 2005**)**. However, considering that 10% of the fields in the survey experience poor drainage on 50% or more of the area and 5% of the fields have upwards of 70% of their soils poorly drained, poor drainage could decrease the probability of irrigation for some fields by upwards of 10%. The fact that there are fields with such drainage characteristics supports our conjecture that there are marginal lands in the valley with irrigation rights which may not be profitable to irrigate in all years.

While the more fine attributes of the soils influenced the probability of irrigation in a way that was consistent with literature and our expectations, the broader classification of soils by capability class did not. It was expected that soils with higher capability class would be increasingly more likely to be irrigated, but this was not the case. Fields with majority class 4 soils were more likely to be irrigated than the other soil classes. This may in part be a result of the soil distribution in the valley. A larger sample size may be required to definitively determine the effect of soil quality on irrigation.

The positive effect of a groundwater right on the likelihood of irrigation is an interesting result. It is possible that relative to surface water irrigation, irrigation with groundwater requires a more substantial investment to establish the needed infrastructure of wells and pumps, and signals a commitment to growing particular crops with irrigation. Following similar reasoning, groundwater irrigation may be correlated with other unobservable characteristics of the operator such as the share of his income that comes from agriculture and whether or not he owns the land being farmed. Increasing share of income from agriculture and ownership of land have been previously shown to be correlated with irrigation adoption and may also affect the irrigation decision on an annual basis (Schuck et al. 2005).

The predictive power of the model is somewhat limited, as indicated by the modified “percent correctly predicted” assessment. This is a likely a result of the large number of unobservable characteristics that play a role in the irrigation decision. In addition to the already mentioned income share from farming and land tenure, such variables as the operator’s age, education and income have been shown to be important in the irrigation adoption decision (Schuck et al. 2005). Even such idiosyncratic variables as whether or not the irrigation equipment is already in a particular field, how much help that farmer has in a particular year and how motivated he may be feeling can determine whether or not the additional income that can be gained from irrigation is worth the effort. Additionally, by only looking at data for individual fields it is impossible to know what the opportunity cost of irrigating a particular field is. From our survey data we know that farmers on average have 7 irrigated fields. Depending on how large a farmer's operation is, and how much irrigation equipment he has, the decision of whether or not to irrigate a particular field may be conditional on what he decided to plant and irrigate on the other fields, and even the fields' proximity to each other.

Moreover, unlike some irrigation adoption studies that have complete information about a farm's irrigation source, the irrigation data used in this study is more limited. A field can have a portion of its area in both a surface and a groundwater right, and while we can make assumptions about which right is the primary one based on the percent of field area it occupies, we cannot be certain. Complicating the matter further, 17% of the fields in our sample do not have a record of a water right from the Oregon Water Resources Department (OWRD 2013). Given that farmers were asked to provide information only about fields that they irrigate, there are several possible reasons for the missing water rights. One is that there could be errors in the data reported by farmers. There is also a possibility of errors in the OWRD water right database. OWRD cautions that some water rights are missing proper spatial descriptions and some may not be in the database at all, particularly among the water rights with oldest priority dates.

Despite some uncertainties with the data, and numerous unobservable characteristics that influence the irrigation decision, the irrigation model incorporates observable measures of climate, land quality and geographic location of fields to estimate the probability of irrigation for a field with water rights that may not be irrigated on an annual basis. The application for which the model was constructed is the prediction of water right use across 547,000 acres of irrigable land. Unlike modeling irrigation districts where water deliveries are metered, sources of water are known, and data on farm size and operators can be widely available, these data were not available for the current study. Of course, it would be nearly impossible to predict whether a specific field will be irrigated in a particular year, even at the present level of accuracy, however, the output of the model provides valuable insight for water managers in the Willamette Valley on how much water is being used, where this use is occurring and where the potential increase in agricultural water demand may come from under conditions of increasing water scarcity.

VII. Conclusion and Implications

This paper investigated the factors that affect farmland rents and a farmer's irrigation decision to yield a greater understanding of the economics of agricultural water use in the Willamette Valley. An ordinary least-squares model was used to determine the implicit prices of water rights, precipitation, soils quality, elevation and temperature. The value of water ranged from $23 per acre foot per year for class 1 and class 2 soils, to around $10 per acre foot per year on class 3 and 4 soils. The value of precipitation was found to be remarkably close to the value of water, at $16.44 per acre foot per year. Fields decreased in value with increasing elevation and increased in value with increasing average minimum growing season temperature. The irrigation decision was modeled using a binary logit model, where the dependent variable was the probability of irrigation for a field, and the independent variables represented vectors of land quality, geographic location and climate. An average probability of irrigation of 0.69 was observed. The probability of irrigation decreased with above average precipitation, elevation, field size, percent of field with poor drainage, available water holding capacity, distance from Willamette River and distance from nearest large city. Probability of irrigation increased with field location in exclusive farm use zoning, for fields irrigated by groundwater, and was greater for soils that were primarily distributed on terraces, compared to soils with greater distribution on hill slopes.

Applying the average probability of irrigation to the 547,000 irrigated acres across the Willamette Valley yields a large acreage of potentially irrigable land that is not being irrigated in a given year. Observed levels of instream flow reflect these facts about the intermittent use of irrigation water rights. Although presently the flows are sufficient in the Willamette River to meet the needs of both junior and senior water right users, given the already apparent effects of climate change on the timing and availability of water, this many not always be the case. As Milly (2008) points out the variability of climatic variables is increasing, raising the odds of both drought and precipitation extremes. This research provides a contribution that will help point toward areas in need of more focused research on the economic impacts of land and water use changes that may result from increasing climatic variability.

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