Valuing Irrigation Water and Irrigation Water Security in the Columbia Basin Project: A Hedonic Analysis of Agricultural Land Sales

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Authorization to Submit Thesis

This thesis of Madison Moore, submitted for the degree of Master of Science with a major in Applied Economics and titled "Valuing Irrigation Water and Irrigation Water Security in the Columbia Basin Project: A Hedonic Analysis of Agricultural Land Sales," has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

The Columbia Basin Project (CBP) is one of the largest agriculturally productive regions in the world but water insecurity and groundwater decline are threatening productivity through losses of irrigated agricultural acreage. The implicit value of irrigation water, differentiated by source, is quantified to provide insight into the value of Columbia River surface water and Odessa Subarea groundwater. Data on CBP land values, spanning August 2014 through August 2017, are used to perform a hedonic analysis. Irrigation water adds significant value to agricultural land; secure surface water rights add more value to agricultural land than insecure groundwater rights. The value added by groundwater irrigation diminishes with well depth. Estimates of CBP region irrigation water value increase our understanding of water pricing such that informed decisions can be made pertaining to efficient water allocation and use.

Acknowledgements

I would like to express my sincere gratitude to my advisor, Dr.Katherine Lee, who gracefully lent her ear as I stumbled through my thesis. The hours she spent patiently and enthusiastically solidifying my theory, editing and correcting my mistakes has brought real-world applicability and purpose to my studies.

I would like to thank my thesis committee who dedicated time and effort to my cause: Dr. Christopher McIntosh who convinced me to attend the University of Idaho and continues to support my goals, Dr. Philip Watson whose vast knowledge has refined my studies, and Barbara Cosens who has brought practicability and alternative perspectives to my work.

I would also like to thank the University of Idaho for funding my education and the support of all those in the Agricultural Economics and Rural Sociology Department. Lastly, I would like to thank everyone who has shaped my work by sharing their knowledge of the Columbia Basin Project and all of those who have provided me with data.

Dedication

I dedicate this study first and foremost to my family who continues to stand by my academic endeavors and to Jacob who has shown undying support. My studies would surely be boring without your fresh perspectives, support and senses of humor.

I would like to extend a special thanks to my grandparents; through your stories of hauling water with horse drawn wagons and tales of breaking ground for irrigation, my interest in water was sparked. Your past experience and hard work has shown that water truly cannot be quantified until one's livelihood depends on it.

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Chapter 1

Introduction

The Columbia Basin Project (CBP) was commissioned in 1943 to mitigate flood risk and promote economic development in Central Washington (Simonds, 1998). Through later agreements, the CBP was expanded to facilitate Columbia River surface water delivery to cropland in the CBP region. As a result, Central Washington has become one of the most productive agricultural regions in the United States; contributing $1.4 billion (2008 USD) to the economy annually (Columbia Basin Development League, 2011). Completion of the CBP was halted in the 1960's due to high costs. As of 2017, 671,000 acres out of the intended one-million cropland acres designated for CBP irrigation are irrigated by surface water. The Odessa Subarea lies in the uncompleted region of the CBP. In the 1960's landowners in the Odessa Subarea purchased water permits under the assumption that surface water would eventually be delivered to the region. As a temporary solution, CBP water permit holders drilled wells and began to irrigate with groundwater. Groundwater has become the primary source of water in the Odessa Subarea serving 170,000 acres of high-valued crops, maintaining agricultural processing facilities and serving as the main source of drinking water for the region (Kahle and Vaccaro, 2015).

Since the onset of groundwater irrigation in the Odessa Subarea, groundwater levels have dropped an estimated 40 million acre-feet.[1] The United States Bureau of Reclamation (2012) estimates that by 2020, 55 percent of wells in the Odessa Subarea will cease production. Groundwater depletion in the Odessa Subarea has resulted in decreased irrigated acreage as groundwater users experience water quality issues and increased pumping costs. Decreased certainty regarding the future of groundwater supplies makes irrigation in the Odessa Subarea less secure than irrigation in the completed portions of the CBP. Water quality issues and

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[1] An acre-foot of water is equal to 325,851 gallons. This quantity is the amount of water needed to cover one-acre of land with one-foot of water.

rising costs decrease the reliability and profitability of groundwater use; between the years of 2005 and 2015, Odessa Subarea potato acreage decreased by 25 percent (Nadreau and Fortenbery, 2017). To address groundwater depletion through Odessa Subarea groundwater replacement the Washington State Department of Ecology has proposed a CBP expansion plan, The Modified Partial Replacement Plan. However, conflicts regarding water pricing and infrastructure costs have stalled CBP expansion.

The objective of this article is to investigate the influence of irrigation water and irrigation water security on agricultural land values in the CBP region. The value added to agricultural land sales in the CBP region by irrigation water is estimated in order to provide knowledge regarding irrigation water pricing. Water security is hypothesized to influence the implicit value of irrigation water; thus the value added by surface water is differentiated from the value added by groundwater. In the CBP, water pricing is used to set water permit prices, recover irrigation infrastructure costs and promote irrigated production. Conflicts regarding permit prices and infrastructure development costs have led to a decrease in high-valued crop production and misuse of groundwater. This data set is used to estimate irrigation water value in order to increase understanding of water pricing in the region. I hypothesize that irrigation water not only increases the value of agricultural land in the CBP region but the value added by irrigation water is influenced by water security. An estimation of irrigation water value can be used to gain a better understanding of water pricing such that losses in irrigated production can be mitigated and groundwater depletion can be addressed.

This thesis provides several contributions to the existing literature. First, I determine the impact of irrigation water on agricultural land value using a hedonic analysis. Although hedonic analyses have been used to successfully determine the influence of irrigation water in other regions, a hedonic analysis has not been used to investigate the CBP region (Swanepoel, 2015; Faux and Perry, 1999; Xu et al., 1993; Young, 1978). Second, I estimate the implicit value of irrigation water differentiated by water source. Water source provides a proxy for water security. Surface water, which is used in the developed portion of the CBP, is more secure than Odessa Subarea groundwater. A measure of water security provides insight into the influence of surface water on the implicit value of irrigation water and the costs of groundwater use. As Wichelns (2010) finds, understanding the incremental costs of groundwater use leads to a better understanding of water values in regions where producers irrigate using both surface water and groundwater. Finally, this analysis it performed using a unique data set of parcel-level land transactions in the CBP region. This data set is hand collected and created using several sources; county assessor data are not used in current CBP investigations. The data presented can be utilized in subsequent studies pertaining to water values, water pricing and infrastructure development.

I measure the impact of irrigation water and irrigation water security on land values in the CBP region. Agricultural land transactions and a hedonic framework are used to estimate the contribution of irrigation water to land values in three counties within the CBP region between the years of 2014 through 2017. The contribution of irrigation, differentiated by water security, is estimated to reveal the implicit value of surface water and implicit value of groundwater. Due to the nature of agricultural land as a long-run investment and a place of residence, the estimation of multiple markets is an issue when dealing with agricultural land parcels. Precautions are taken to measure, properly quantify and justify the inclusion of variables in this investigation. The data is rigorously tested; statistical issues pertaining to multicollinearity, heteroskedasticity, model specification and omitted variable bias are addressed.

I find that irrigation water and irrigation water security have explanatory power in agricultural land sales in the CBP region. Surface water irrigation is found to exert a premium which significantly increases the value of agricultural land. The premium derived from surface water, which is considered more secure than groundwater, is hypothesized to arise from water security. Groundwater irrigation also significantly increases land value but groundwater premiums decrease as a function of well depth, reflecting the costs of groundwater depletion. This model estimates the influence of surface water and groundwater on irrigation water premiums and the added value of one acre-foot of irrigation water. Estimates can be used to identify the point at which groundwater users cease to irrigate, choosing dryland production over irrigated production. An understanding of surface water premiums and groundwater costs also allows for the quantification of water prices. A loss in irrigated production in the Odessa Subarea is negatively impacting producers, processors and municipalities; quantifying water values is important in correctly pricing water such that high-valued irrigated production is not lost.

The organization of this paper is as follows; Chapter 2 provides background on the CBP and Odessa Subarea as well as an overview of water security and historic groundwater depletion in the region. Chapter 3 provides a review of hedonic theory and existing literature. Chapter 4 provides an overview of the data set and describes the empirical methods used in determining an appropriate model. The final model, along with key findings, are presented in Chapter 5. Chapter 6 provides a discussion of the implications of irrigation water and irrigation water security on agricultural land values in the CBP region.

Chapter 2

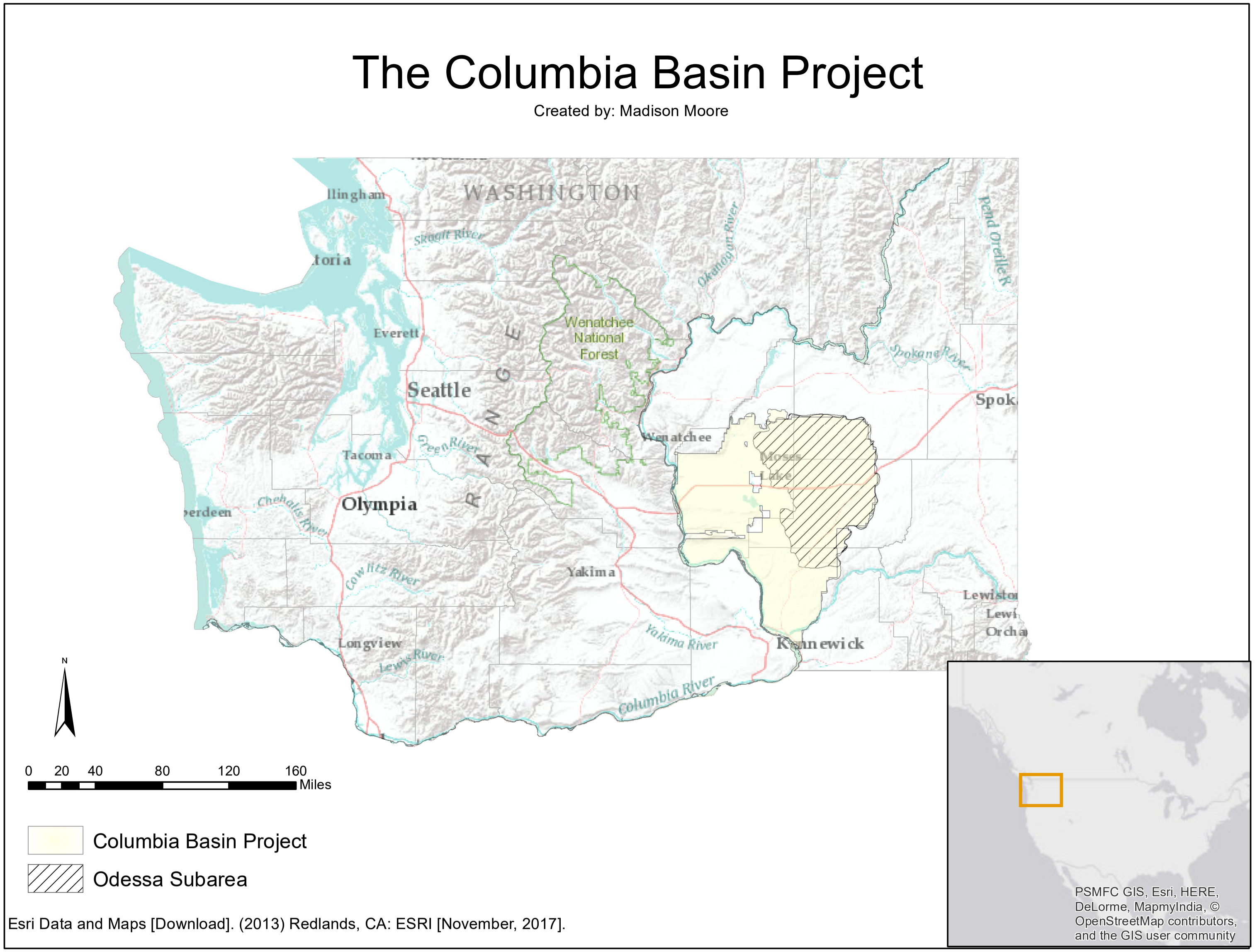
Background

2.1 Study Area

The CBP is located east of the Cascade Mountain Range (Figure 2.1) and is roughly two-million acres. 1,095,000 of these acres are classified as irrigable while the other half are non-irrigable. Irrigable acres are subdivided into four categories; class 1 and class 2 consist of highly productive land suitable for a variety of crop production. Class 3 and class 4 are also irrigable but less productive due to soil type, topography, water-holding capacity and fertility (Svendsen and Vermillion, 1994). Over 57 percent of soil in the CBP region is considered class 1 or class 2 irrigable soil; productive soil and moderate topography makes the CBP region an ideal location for high-valued crop production.

The climate of the CBP region is semi-arid; average annual precipitation ranges from five to eleven inches per year, most occurring as snow fall (Kahle and Vaccaro, 2015). Seasonal precipitation increases the value of reliable irrigation; permanent crops which require large water allotments during drought season are grown in areas where water is more secure. In the developed portion of the CBP, surface water is used to irrigate high-valued permanent crops including apples, cherries, pears and grapes (See Appendix A, Figure 6.1). In the Odessa Subarea (Figure 2.2), groundwater is used to irrigate non-permanent, yet still high-valued, crops including potatoes, onions, corn, asparagus, peppermint, canola, spelt, triticale, alfalfa, bluegrass seed, beans and peas (United States Bureau of Reclamation, 2012).

The value of crop production in the four counties which compose the CBP region (Grant, Franklin, Adams and Lincoln County) is estimated at $122 million (raw products) and $189 million (processed products) (Washington State Office of Financial Management, 2011). As of 2012, Grant County was the largest sole contributor to Washington State's agricultural



Esri Data and Maps [Download]. (2013) Redlands, CA: ESRI [November, 2017].

Figure 2.1: Map of the Columbia Basin Project

revenue; Grant County contributed \$11 million in crop and animal production cash receipts and composed 13 percent of all Washington State agricultural and food processing employment (Washington State Agriculture & Food Processing, 2015). Grant County is located in the developed portion of the CBP region where secure irrigation water allows for high-valued crop production. As of 2007, the United States Bureau of Reclamation (2012) reports there are 2,534 irrigated farms in the Odessa Subarea;[1] the amount irrigated on each farm is approximately 333 acres. Wheat, hay and potatoes consist of 91 percent of irrigated crops grown in the region (U.S. Bureau of Reclamation, 2012). In 2012, wheat accounted for 63.4 percent of the total acreage (irrigated and non-irrigated) in the Odessa Subarea. Wheat is one of the lowest-valued crop types in the CBP region; wheat is the crop of choice for dryland production and it is the primary rotation crop on irrigated acreage.

The CBP is the Columbia River's largest irrigation infrastructure; the Grand Coulee Dam and Lake Roosevelt are the main sources of irrigation water for the CBP. The Grand Coulee Dam was developed in the late 1930's to stabilize Columbia River base flows but quickly became a major power generating facility during World War II (Simonds, 1998). Flood control and power generation are the primary objectives of several transboundary, domestic and regional agreements which govern Columbia River water use. Hydropower generated by the Columbia River provides 55 percent of the electricity in the Pacific Northwest (Harrison, 2008). Other demands for in-stream use include; base flows for salmon migration, fishing and recreation. Competing demand for irrigation, power generation and in-stream use has prevented full irrigation water allocation and stalled irrigation infrastructure expansion.

Water delivery to the developed portion of the CBP is reliable and subsidized; this makes surface water use in the CBP region highly secure. CBP surface water users pay a normalized[2] cost for permits and yearly water delivery. Surface water delivery is dispersed in the form of water allotments which range from 3 acre-feet per year to 4 acre-feet per

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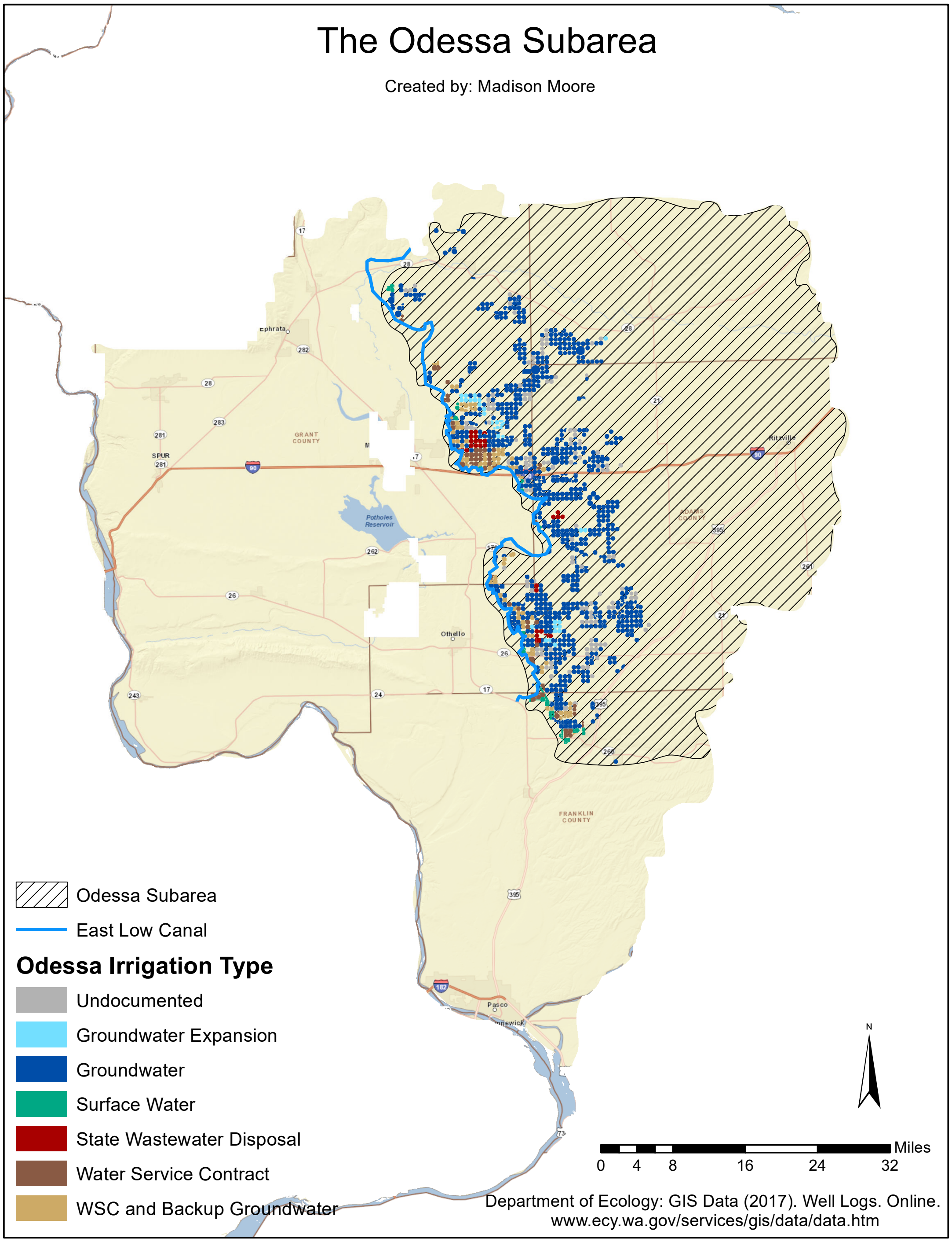
[1] The Odessa Subarea is operated by the East Columbia Basin Irrigation District and it is composed of four counties; Grant, Franklin, Adams, and Lincoln counties

[2] Water users pay a set price for surface water permits regardless of water delivery costs. Water delivery costs increase as proximity to irrigated infrastructure decreases.



The Odessa Subarea

Created by: Madison Moore

Department of Ecology: GIS Data (2017). Well Logs. Online. www.ecy.wa.gov/services/gis/data/data.htm

Figure 2.2: Map of Irrigation Source in the Odessa Subarea

year depending on soil class[3] (Svendsen and Vermillion, 1994). All irrigable soil classes are considered when allotting surface water. Permit prices include operation and maintenance expenses as well as infrastructure repayment. Producers pay a relatively small percentage of total infrastructure development costs and water delivery; the CBP is highly subsidized by the Grand Coulee Power Complex power generation and Washington State tax revenue (Svendsen and Vermillion, 1994).

In the West, water adjudication is based on the doctrine of Prior Appropriation[4] meaning that in water short years water is allocated based on seniority of water rights (Washington State Legislature, 1917). In the context of this investigation, the term "water rights" is used to distinguish between surface water and groundwater use. Both CBP surface water users and Odessa Subarea groundwater users have CBP water rights but the security of water rights depends on water source. As seen in Figure 2.2, cropland west of the East Low Canal is irrigated via surface water; this region is referred to as the "the developed portion of the CBP region." The developed portion of the CBP region consists of 671,000 acres of surface water irrigated cropland. CBP surface water rights are some of the oldest and most subsidized in Washington State; high-priority water rights, the expectation of future water supplies and decreased risk associated with reliable water quality makes CBP surface water permits secure (Peters, 2009). The undeveloped portion of the CBP, seen in Figure 2.2, is referred to as the Odessa Subarea. Odessa Subarea groundwater irrigators are CBP permit holders using groundwater as a temporary source of irrigation. Groundwater as a source of irrigation by nature is less secure than CBP surface water. Groundwater users pay full water pumping and delivery costs (as opposed to CBP surface water users) and assume water quantity and quality risks. Groundwater users pay to install, pump and deliver water to cropland whereas water delivery is subsidized for CBP surface water users.

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[3] Large and reliable water allotments allow for the growth of water consumptive permanent crops such as apples, cherries, pears and vineyards as well as water consumptive row crops (Natural Resources Conservation Service: Washington, 1985).

[4] In 1917, Washington State adopted the Water Code which has allowed the doctrine of Prior Appropriation to become an essential element of water governance in the state. According to Washington State Water Code, water rights are allocated based on "first in time, first in right."

Water security in the Odessa Subarea is variable; Figure 2.2 depicts areas of groundwater irrigated cropland considered for surface water replacement under The Modified Partial Replacement Plan. Groundwater is used throughout the Odessa Subarea but only groundwater users located near the East Low Canal expect surface water irrigation within the near future. Producers located within The Modified Partial Replacement Plan project area are more likely to grow high-valued row crops due to an increase in water security which is derived from the expectation of future surface water delivery. Surface water is recognized as the most secure source of irrigation water in the CBP region; surface water is more secure than the expectation of future surface water or groundwater. This investigation treats the developed portion of the CBP region as secure, due to surface water use, and the Odessa Subarea as insecure, due to groundwater use.

When CBP expansion was stalled in the 1960's, Odessa Subarea producers were granted permission to use groundwater in order to satisfy their irrigation permits. Groundwater use was not mitigated because CBP expansion was expected to occur within a decade; high costs continue to prevent infrastructure expansion. Groundwater depletion results as the unintended consequence of the partially developed CBP. Water security decreases as well-depth increases. The average Odessa Subarea well is 800 to 1,000 feet deep and the deepest wells are up to 3,000 feet deep (United States Bureau of Reclamation, 2012). Deep-water pumping is associated with high-temperature water, high-salinity, and concentrations of elements. For municipalities and processing plants, low-quality water results in increased treatment costs, unsafe drinking water and sometimes unusable water (Kahle and Vaccaro, 2015). The security of groundwater will continue to decline as producers deepen wells in order to sustain cropping practices.

Declining aquifer depth, due to groundwater pumping, has decreased high-valued crop acreage in the CBP region. As of 2012, only 35 percent of irrigation wells in the area were suitable to meet irrigation requirements for water-using crops (United States Bureau of Reclamation, 2012). The United States Bureau of Reclamation (2012) finds that the security of water in the region will continue to decline as farmers deepen wells in order to sustain cropping practices. In the Odessa Subarea, water permit holders are ceasing to use groundwater, in turn producing via dryland production. Rising cost and deteriorating water quality significantly impact the CBP region by decreasing the production of high-valued crops (Nadreau and Fortenbery, 2017). Wichelns (2010) finds that decreasing risk, through correct water pricing derived from water values, can incentive producers to grow high-valued crops and maximize output per-unit of water. An investigation of irrigation water value can shed light on how water pricing can be used to incentivize producers, recover the costs of irrigation and decrease groundwater depletion.

Chapter 3

Literature Review

3.1 Hedonic Valuation

Rosen's (1974) two-stage theoretical model is seminal in developing theory regarding the value of goods with heterogeneous qualities. In Rosen (1974), the price of a good is a function of the attributes embodied in the good; each attribute has a unique, implicit price.[1] The contribution of each attribute can be determined through the regression of a good's price on given attributes. Rosen's model is based on three conditions; 1) equilibrium in the market place, 2) perfect information and 3) zero transaction costs. The first assumption implies that consumers choose a combination of attributes such that the marginal value added equals the marginal rate of substitution between a given attribute and an alternative attribute. The first assumption indicates that an attribute's implicit value can be revealed through a hedonic analysis. The second assumption can be generalized to assume near perfect information between buyers and sellers such that true price is realized. While the third assumption, zero transaction cost, is unrealistic- the existence of transaction costs, as long as they are small, does not negate the validity of a hedonic analysis (Heffner, 1999).

Hedonic analyses are used extensively in the assessment of influential urban and rural land value attributes (Miranowski and Hammes, 1984; Gardner and Barrows, 1985; Dunford et al., 1985; Torell et al., 1990). Land is unique, as it is spatially heterogeneous, durable and fixed in space (Hotelling, 1931; Von Thünen, 1966). As a result, land value is highly variable, as are the attributes which drive land value. Heterogeneity makes hedonic analysis an ideal tool when attempting to explain variations in land and water values (Heffner, 1999). In the west, agricultural water and agricultural land are typically bundled (Rosen) goods (Crouter,

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[1] Implicit value (price) refers to the added value of a good; this implicit price does not have a true monetary value. Economist often use hedonic valuation to derive the implied monetary value of a good's attributes.

1987). The added value of water is embodied in land sale price, thus the implicit value of water can be estimated though a hedonic analysis of land transactions.

Following Rosen's framework, the first-stage regression coefficients inform the marginal, herein referred to as implicit value, of each characteristic. In the case of agricultural land, the dependent variable is land sale price and the independent variables are the characteristics of sold land such that:

$$P_i = \beta_0 + \beta_i X_i + \varepsilon_i \tag{3.1}$$

Where X_i is a vector of attributes regressed on the observable price, P_i; note that ε_i is a random error term and β_0 is the intercept. A vector of P_i denotes packages of consumer preferences and market transactions. The partial derivative of price with respect to the i-th characteristic, $\dfrac{\partial P(X_i)}{\partial (X_i)}$, represents the implicit value evaluated on the numerical values of X_i. This is the amount a buyer is willing to pay and a seller is willing to accept for an additional unit of a good, *ceteris paribus* (Coelli et al., 1991).

Heterogeneity in the market place should be considered when interpreting first-stage results. In this analysis, the market place represents differentiated buyers and sellers. Under this condition, attributes are differentiated but assumed to be impossible to disentangle (Rosen, 1974). This assumption is supported by CBP region production, buyers and sellers are differentiated by market entry costs, crop-derived profitability and willingness to invest. Differentiated attributes indicate differentiated markets. An implicit value beyond the added value of attributes exists indicating that differentiated markets should be considered when determining sale price. The derivation of a market representing multiple buyers and sellers allows for the estimation of marginal values across multiple sectors.

Several criticisms have arisen regarding the *a priori* restrictions asserted on the functional form of Rosen's (1974) first-stage regression (Brown and Rosen, 1982). The estimates produced in the second-stage regression result in duplicated first-stage estimates if theoretical restrictions are ignored. Examining differentiated markets allows for control over individual characteristics and the deduction of individual price functions (Heffner, 1999). Differentiated attributes and markets are considered and functional form is thoroughly investigated in this study but second-stage estimation is not performed.

Traditional studies divide land characteristics into three groups but this study is divided into four; the productive component, consumptive component, spatial component and water component (Coelli et al., 1991; Xu et al., 1993; Bastian et al., 2002). The productive component includes factors such as precipitation, soil quality and buildings or improvements; it is defined as the present value of expected returns to land (Xu et al., 1993). The productive component is represented by several variables in this model which distinguish between irrigated acreage, dryland acreage, acreage containing a homesite, non-cropped acreage and other types of acreage. These variables are referred to as land class variables from hereon. Permanent crop values and improvement values are also included in the productive component of this investigation. The consumptive component denotes rural amenities (i.e., the intrinsic value derived from living in a rural area) and the long-run value of consumption (e.g., place of residence). While imperfect, the consumptive component is captured by three binary variables indicating land zones (i.e., commercial, suburban or other). The spatial component is included because space is important in determining the cost of infrastructure. Spatial attributes include the distance from a given parcel to the East Low Canal and the distance from a given parcel to the nearest town. This study also includes a water specific component which indicates well depth and land location. A well depth variable allows for an estimation of the per-unit added value of groundwater while land location variables differentiate irrigation water by source. The water component provides insight into the influence of water security and the costs of groundwater use.

Understanding the economic intuition which drives attribute selection is essential in investigating land value. Theory separates economic analyses from erroneous “kitchen sink” statistical analyses.[2] Guided by economic intuition, this model includes the following at-

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[2] A “kitchen sink” statistical analysis refers to the use of every possible independent variable in order to explain the dependent variable. This increases the probability of deriving statistical significance when in fact there is none.

tributes; land class, improvement value, permanent crop value, water source, distance, presence of residential or commercial zones and well depth. Land class is divided into several variables to utilize full information and conform to findings of previous studies (Bastian et al., 2002). Soil type is not specified due to hard-to-obtain data and due to the homogeneity of irrigable land in the CBP region. Specifics regarding variables and data are discussed in Chapter 4.

3.2 Hedonic Valuation of Water

Hedonic analysis is becoming a common tool in western water policy. The implicit value of water can be deduced from hedonic land valuations such that water pricing can be better understood. Various studies have estimated the marginal impact of irrigation water on agricultural land values (Miranowski and Hammes, 1984; Torell et al., 1990; Coelli et al., 1991; Faux and Perry, 1999; Heffner, 1999). Notably, Crouter (1987) finds that water functions are often linear and inseparable from land. When determining the value of water, land values should be taken into account due to the co-dependent relationship of water and land.

It is common to account for distance in hedonic analyses (see Rosen, 1979; Coelli et al., 1991; and Xu et al., 1993) but the precision of geographic information systems (GIS) wasn't recognized until recently. Recent investigations suggest the importance of incorporating space in land value analyses; GIS allows for location based accuracy and parcel specific estimations of land values (Bastian et al., 2002). A growing number of studies are incorporating GIS in land value investigations. For example, Kennedy et al. (1996) and Bastian et al. (2002) use GIS to define distance functions, quantify irrigated acreage productivity and identify wildlife habitat. GIS data can be used to replace binary indicator variables such that parcel-specific attributes can be derived (Bastian et al., 2002). GIS derived variables are used in this investigation of the CBP to accurately represent parcel location and define attributes.

Swanepoel (2015), finds that separation of indexed variables allows for the determination of specific attribute properties. Swanepoel's (2015) investigation separates typically aggregated variables, including water source and land classifications, such that the impact of groundwater and surface water can be determined. This follows suit with investigations which incorporate various water related variables, including well depth, in the determination of farm land values. Significant results are found when well depth is incorporated. Well depth is used in this investigation of the CBP region to understand the incremental cost of groundwater use and the value of irrigation water differentiated by water security.

3.3 Measuring the Value of Water in the Columbia Basin Project

Various benefit-cost analyses have been used to estimate the influence of irrigation water in the CBP region and compare irrigation infrastructure designs. Several studies have estimated water value in the CBP region, these studies are commissioned by the United States Bureau of Reclamation and the Washington State Department of Ecology. The United States Bureau of Reclamation's (2012) economic impact assessment of irrigation expansion is seminal in establishing The Modified Partial Replacement Plan as the optimal Odessa Subarea groundwater replacement plan. The implicit value of water is estimated in the United States Bureau of Reclamation's investigation and used to calculate the benefit-cost ratio[3] and value added by The Modified Partial Replacement Plan. The United States Bureau of Reclamation (2012) calculates the benefit-cost ratio of The Modified Partial Replacement Plan, determining it to be 1.008. Thus, groundwater replacement is determined to be of optimal value. The U.S. Bureau of Reclamation (2012) finds that the market value of land in the Odessa Subarea rises by approximately $4,000 if groundwater is replaced via The Modified Partial Replacement Plan. Market value is an indicator of the implicit value of irrigation water; the market value found in the United States Bureau of Reclamation's (2012) investigation is used in subsequent studies as a proxy for water value. Irrigation infrastructure

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[3] The benefit-cost ratio is an indicator used in benefit-cost analyses to assess the monetary value of a project. It is simply the ratio of benefits to costs; projects are considered optimal when the benefit-cost ratio is greater than one.

development and water permit prices are analyzed using this proxy.

Conflict has arisen regarding the United States Bureau of Reclamation's estimates of the implicit value of irrigation water. Whittlesey and Butcher (2012) disagree with estimated water values and find that the United States Bureau of Reclamation's benefit-cost ratio miscalculates the value of groundwater replacement. In the United States Bureau of Reclamation's (2012) study, the value added by implementing The Modified Partial Replacement Plan is less than the costs of infrastructure development. The United States Bureau of Reclamation estimates irrigated infrastructure development costs to be approximately $12,000 (Whittlesey and Butcher, 2012). Despite costs being greater than benefits, The Modified Partial Replacement Plan has a positive benefit-cost ratio. Whittlesey and Butcher (2012) find that miscalculated water values have distorted the estimated benefit-cost ratio and resulted in overvaluing water.

The Columbia-Snake River Irrigators Association (CSRIA) has also estimated the implicit value of irrigation water and used it to evaluate alternative irrigation infrastructure. The CSRIA finds the market value of an alternative privately funded infrastructure project to be $50 million (Columbia-Snake River Irrigators Association, 2012). The CSRIA's calculations are based on estimates of the implicit value of water and estimates of water prices. Differences between the United States Bureau of Reclamation and CSRIA estimates causes ambiguity regarding the implicit value of irrigation water. Young (1978), finds that estimates of water price and water value are useful in examining proposed water development projects, determining infrastructure costs, and addressing water rights claims. Increased knowledge regarding the implicit value of irrigation water in the CBP region allows for a better understanding of the benefits and costs of irrigation water infrastructure. Furthermore, water value estimates can be used in developing water prices which recover irrigation infrastructure costs and reflect the scarcity value of water (Wichelns, 2010).

Chapter 4

Data

4.1 Data

TaxSifter is the common data base used by Grant, Franklin, Adams and Lincoln County assessors to record historic appraisal data. Agricultural land parcels sold between August 2014 and August 2017 in Grant, Franklin, Lincoln and Adams Counties are recorded using TaxSifter.[1] Observations in this data set are differentiated by location; parcels are categorized as within or outside of the CBP boundary, and within or outside of the Odessa Subarea. TaxSifter provided data on parcel sale price, acreage, sale date, production type, improvement values, permanent crop values, existence of residence and land classifications (See Table 4.1). In TaxSifter, parcel attributes are recorded as land classifications; each county has a unique set of classification codes based on agricultural production type (i.e. irrigated or dryland) and soil type (i.e. class one cropland versus class three cropland).

Using assessor data, I condensed acreage into six major land types and three binary designations. Land classes are recorded as irrigated cropland, non-irrigated cropland, land with a residential site, pasture and non-cropped land. Binary designations identify zoning types and are classified as commercial, suburban or other types of zoning. Classifications which combine water and land attributes are supported by Crouter's (1987) findings of inseparability between land and water in the West. The variables in this model act as both land class attributes and water attributes.

The remaining variables in this investigation are created using ArcGIS[2] spatial data and obtained through several sources. Grant County and Franklin County parcel maps are provided by county assessors and Adams County parcel boundaries are provided by

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[1] Agricultural land sales are found by using the TaxSifter "Sales Search" function.

[2] ArcGIS is a commonly used Geographical Information System; it is refered to as "GIS" throughout the text. This investigation utilizes GIS in the calculation of several spatial and water related variables.

the School of Environmental and Forestry Services at the University of Washington (Grant County, 2017; Franklin County, 2017; Lincoln County, 2017; Adams County, 2017; Univeristy of Washington, 2013). Lincoln County is omitted from this analysis due to corrupt ArcGIS data.[3] CBP boundaries and spatial characteristics, including canal infrastructure maps are obtained from the United States Bureau of Reclamation (Stolsig, 2017). Odessa Subarea boundaries are obtained from the Washington State Department of Agriculture (Beale, 2017). Parcel maps, canal maps, and well logs are used to calculate distance to towns, distance to canals and well depth (Grant County, 2017; Franklin County, 2017; Lincoln County, 2017; Univeristy of Washington, 2013; Stolsig, 2017; Washington State Department of Ecology: GIS Data, 2017). A full description of the variables used in this analysis can be found in Table 4.1.

Sale price is recorded as the total transaction price. Transactions containing more than one parcel are compiled into single observations to avoid bias and unit issues. Land class variables, permanent crop values and improvement values are summed for transactions containing multiple parcels. Town distance, canal distance and well depth are averaged. Permanent crop values and improvement values are assessed values; permanent crop values represent the assessed dollar value of orchards and vineyards. Improvements to land include; houses, shops, agricultural storage and irrigation infrastructure. Improvement values and permanent crop values are used to distinguish between the improved and unimproved agricultural cropland market while zoning distinctions are used to indicate alternative, residential and commercial markets.

The East Low Canal is mapped and parcel centroids[4] are calculated in order to estimate the distance from the East Low Canal to given parcels. Distance to town is created by calculating the distance from each parcel to the three largest towns in the Columbia Basin;

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[3] Distance can not be computed given current Lincoln County shape files. Despite the absence of Lincoln County observations, this data set provides a robust representation of agricultural land sales in the CBP region.

[4] Centroids indicate the mathematical center of given parcels. centroids are found in order to provide reliable and uniform measurements of distance.

Table 4.1: Data Description

Variable	**Unit**	**Description**
Sale Price	Dollars	Total transaction value (CPI adjusted)
Year		2014, 2015, 2016, 2017
Month		January-December
County		Grant, Franklin, Adams
Productive Component		
Improvement Value	Dollars	Infrastructure investments (CPI adjusted)
Permanent Crop Value	Dollars	Value of orchards and vineyards (CPI adjusted)
Irrigated	Acres	Presence of irrigated agriculture
Dryland	Acres	Presence of non-irrigated agriculture
Homesite	Acres	Presence of rural residence
NonCrop	Acres	Presence of non-cropped, CRP or scrubland
Pasture	Acres	Presence of grazing land
Other	Acres	Presence of land with various non-agricultural designations
Water Component		
In CBP		=1 if parcel is located in the developed CBP
In Odessa		=1 if parcel is located in the Odessa Subarea
Well Depth	Feet	Weighted average of wells on site
Consumptive Component		
Commercial Zone		=1 if zoned for commercial use
Suburban Zone		=1 if zoned for suburban use
Other Zone		=1 if zoned for utility value or other designation
Spatial Component		
Canal Distance	Miles	Average distance from parcel to East Low Canal
Town Distance	Miles	Average distance from parcel to nearest town
Acres	Acres	Size of parcel
PricePerAcre	Acres	Total sale price divided by transaction acreage

the shortest distance represents the town distance variable. The three towns are; Pasco (population of 70,500), Moses Lake (population of 22,600) and Othello (population of 8,100). Although the difference in population between the three towns is great, the location of the CBP region's economic center, Pasco, makes travel to smaller but closer towns feasible.

Well depth is calculated using the Washington State Department of Ecology Well Log GIS database (Washington State Department of Ecology: GIS Data, 2017). Wells primarily used for irrigation are recorded whereas resource protection, decommissioned or residential wells are omitted. Since parcels in the data set contain multiple wells, the average well depth is calculated. This investigation follows suit to Swanepoel's (2015) study which uses weighted well depth and well interaction terms to capture groundwater values.

Cleaning and formatting the data is perhaps the greatest challenge faced in this analysis. Due to the nature of data collection and data quality, multicollinearity[5] is expected to be a major modeling issue. If multicollinearity is present, the true influence of predictor variables cannot be determined. To address multicollinearity, several versions of the data set are created and tested. Observations are combined by excise number[6] resulting in the summation and averaging of various independent variables and the loss of information regarding specific parcel characteristics. Combining parcels by excise number decreases total observations from 1,461 to 535. The data set is also condensed from the original eighteen land class variables to six continuous variables and three binary variables. Although some loss of soil type and land productivity information occurs, the data is condensed to mitigate disparity between county assessments and to create robust water variables. A summary of the data set is provided in Table 4.2.

Agricultural land sales with a value of less than one-hundred dollars are not included in this investigation because such sales are assumed to be an unrepresentative subset of the agricultural land market. Examples of such markets include “under the table” [7] transactions and deeded lands between family members. Non-market transactions, such as these, distort coefficients and do not allow for true estimates of the independent variables. Inactive parcels[8] are also not recorded.

To correct for multicollinearity, all independent variables are in total variable acreage units. Thus, the dependent variable, *Sales Price*, represents the total price-per-transaction. This decision is supported theoretically; total acreage size, land class and sales price do not exhibit a linear relationship. The value added by one-unit of irrigation to one-acre of

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[5] Multicollinearity is present when two or more predictor variables are correlated; multicollinearity does not reduce the significance of the model as a whole but it does decrease the reliability of independent variable coefficients.

[6] Parcel excise number is the unique transaction number used to identify the various parcels sold in one transaction.

[7] “Under the table” transactions are sales which occur in secret or without full information.

[8] Inactive parcels are parcels which have been combined during sale or no longer exist. Such sales are not accurately represented by land attributes.

Table 4.2: Summary Statistics

Variable	**Obs.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Sale Price	535	868,563.6	1,480,991	1,647.88	13,400,000
Year	535	2,015.57	0.98	2014	2017
Month	535	6.87	3.65	1	12
County	535	1.67	0.83	1	3
Productive Component					
Improvement Value	535	77,638.4	337,019.4	0	6,848,868
Permanent Crop Value	535	30,844.2	178,116.1	0	2,423,790
Irrigated	535	68.89	119.93	0	1,154.88
Dryland	535	129.37	412.36	0	5,417.18
Homesite	535	1.02	3.56	0	60.01
Pasture	535	19.69	128.81	0	2,324.01
NonCrop	535	33.56	308.75	0	6,787
Other	535	2.08	5.45	0	77.8
Water Component					
In CBP	535	0.579	0.494	0	1
In Odessa	535	0.25	0.44	0	1
Well Depth	535	77.28	203.25	0	1,934
Consumption Component					
Commercial Zone	535	0.01	.08	0	1
Suburban Zone	535	0.17	0.38	0	1
Other Zone	535	0.04	0.19	0	1
Spatial Component					
Canal Distance	516	15.74	11.07	0	46.4
Town Distance	516	20.71	11.09	1.28	61.02
Acres	535	259.95	564,79	0.52	6,788
PricePerAcre	535	13,734.95	55,177.82	101.51	1,153,846

land versus the value added by one-unit of irrigation to one-hundred acres of land differs. Economies of scale occur in irrigated agriculture; thus, acreage is suspected to have a large and non-linear impact on price.

Rosen's (1974) model indicates that there are several market structures, differentiated by buyer and seller characteristics, which must be considered when estimating a hedonic model. A CBP agricultural land market model represents the most general case composed of various intersections between buyers and sellers. Under this condition, products are differentiated and it is assumed that it is not possible to disentangle packages (Rosen, 1974). This assumption is supported by CBP region production and residential market characteristics. The market for agricultural land in the CBP region is differentiated by the presence of residential and commercial zoning. In this study, the added value of commercial and residential zoning cannot be calculated through a simple subtraction of zoning values from cropland values. When packages containing cropland and commercial or residential zones are untied, the true value of cropland is not obtained. Thus, cropland markets are not adjusted for the presence of commercial and residential markets.

4.2 Ordinary Least Squares Model

Faux and Perry (1999) indicate that functional form specification is highly dependent on the nature and quality of data. To avoid misspecification of functional form and biased or misleading results, I perform a thorough examination of the data set, beginning with a standard linear regression. The linear regression takes on the form:

$$Y_i = \beta_0 + \beta_i X_i + \varepsilon_i \tag{4.1}$$

Y_i represents the total sale price of transaction i, β_0 is the model constant and ε_i is the error term. X_i is composed of the variables seen in Table 4.2 and corresponding β_i's represent variable estimates. Variables in the linear regression are categorized by the productive component, consumptive component, spacial component and water component. The water component is the focus of this investigation and includes the variables; *Well Depth*, *In CBP* and *In Odessa*. The productive component consists of *Improvement Value* and *Permanent Crop Value* as well as several land class variables; *Irrigated*, *Dryland*, *Homesite*, *NonCrop*, *Other* and *Pasture*. The consumptive component; *Commercial Zone*, *Suburban Zone* and *Other Zone*, indicates the presence of non-agricultural land markets while the spatial component provides insight into location-based attributes. The spatial component includes; *Canal Distance* and *Town Distance*.

The influence of surface water is measured through the use of CBP region boundaries. Parcel boundaries and identification numbers are used to discriminate between parcels residing in the Odessa Subarea and parcels residing in the developed CBP region. Surface water in the developed CBP region is secure compared to Odessa Subarea groundwater. Due to this difference in water security, parcels with CBP surface water rights are hypothesized to exhibit sale price premiums. The presence of an agricultural well indicates irrigated agriculture, thus groundwater use is also hypothesized to have a positive influence on agricultural land value.

All land class variables are expected to exhibit a positive relationship with the sale price of agricultural land in the CBP region. The presence of residential property and the presence of irrigation are expected to have the greatest impact on agricultural land sale values. Non-cropped and pasture land are expected to have a lesser but still positive impact on agricultural land sale values. The value of improvements and permanent crops as well as the presence of commercial zones are expected to positively influence agricultural land value. The influence of suburban and other types of zones are ambiguous. Competitive zoning between agricultural and suburban land in the CBP region has increased the value of agricultural land. In the case where an agricultural land is zoned for future suburban development, the value of this land may increase due to housing demand or it may decrease due to a loss of agricultural production. Town distance is expected to have a negative influence on parcel sale price; as distance to town increases, land value decreases.

Interaction terms are created and used to measure the influence of water security and water rights on the premium created by the presence of irrigation. *Irr*WellDepth* is used to determine the influence of groundwater as an irrigation source. This model cannot capture the full effects of groundwater use since depletion is realized over a long time-horizon but *Irr*WellDepth* does provide insight into the influence of groundwater use on irrigation water premiums. Increased well depth is associated with increased pumping costs and decreased water quality. *Irr*WellDepth* is expected to have a negative relationship with agricultural land prices. *Irr*InCBP* is used to determine if secure water rights impact irrigation premiums. The developed CBP region represents secure surface water rights whereas the Odessa Subarea represents insecure groundwater rights. Thus, the use of surface water irrigation in the developed CBP region is expected to generate a greater premium than the premium generated by groundwater use in the Odessa Subarea.

County and month of sale are suspected to be correlated with the independent variables in this model. Time-based categorization of independent variables conforms to economic intuition; prices fluctuate monthly and yearly, categorization minimizes the influence created by differences in time. The correlation between county and other variables is supported by Xu et al.'s (1993) study which finds that agricultural land markets in Washington State are differentiated by county. Fixed effects allow for a measurement of change within groups through out time. Categorical attributes, such as time and county in this model, are held constant throughout individual variables. This technique decreases noise across groups and, if performed properly, allows for increased precision in coefficient estimation and a decrease in omitted variable bias. County and time fixed effects are tested in the linear regression. Summarized linear regression results can be seen in Table 4.3 while full regression results, including time and county coefficients, are found in Appendix A.2. In Table 4.3, columns one through three denote linear models with varied fixed effects while columns four through six denote log-linear models with varied fixed effects.

An analysis of several linear models with and without fixed effects indicates that time, including month and year, and county are both significant. While p-values do not indicate that individual time and county variables (i.e, year 2015 versus year 2016) are significant, a F-test for joint hypotheses[9] indicates that both county and month fixed effects improve

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[9] A F-test for joint hypotheses is used to determine whether coefficients are significantly different from zero. If the hypothesis is rejected, the variables being tested are jointly significant in explaining model variance.

Table 4.3: Summary Table: Linear and Log-Linear Regressions With and Without Fixed Effects (FE)

Dependent Variable	**Sale Price** (1)	**Sale Price** (2)	**Sale Price** (3)	**Logged Price** (4)	**Logged Price** (5)	**Logged Price** (6)
Irrigated	10271.040***	10162.930***	10266.590***	0.00511***	0.00483***	0.00492***
	(17.66)	(17.39)	(17.69)	(6.78)	(6.51)	(6.63)
Dryland	760.068***	765.703***	822.550***	0.000893***	0.000800***	0.000846***
	(7.54)	(7.53)	(8.05)	(6.16)	(6.20)	(6.48)
Homesite	34303.390***	31948.630**	33874.390**	0.0360**	0.0320*	0.0341*
	(3.28)	(3.01)	(3.16)	(2.66)	(2.38)	(2.50)
In CBP	59601.290	30551.870	19638.360	0.552*	0.521**	0.0512**
	(0.42)	(0.21)	(0.14)	(3.00)	(2.88)	(2.83)
Canal Distance	15580.720**	17168.650**	19049.820***	0.0240***	0.0266***	0.0284***
	(2.88)	(3.13)	(3.47)	(3.43)	(3.83)	(4.04)
Well Depth	193.669	165.459	138.190	0.000893**	0.000867**	0.000841**
	(0.81)	(0.69)	(0.58)	(2.89)	(2.84)	(2.75)
*Irr*WellDepth*	-2.269*	-2.114*	-2.11**	-0.00000284**	-0.00000276**	-0.00000276**
	(-2.78)	(-2.57)	(-2.60)	(-2.68)	(-2.65)	(-2.66)
*Irr*InCBP*	-534.765	-333.339	-198.220	0.00405**	0.00463***	0.00477***
	(-1.17)	(-0.41)	(-0.25)	(3.95)	(4.53)	(4.65)
Constant	-195023.900*	-426104.100*	-346003.000	11.493***	11.512***	11.585***
	(-1.17)	(-1.70)	(-1.38)	(53.11)	(36.26)	(36.24)
Year & Month FE		X	X		X	X
County FE			X			X
Observations	516	516	516	516	516	516
R^2	0.705	0.716	0.722	0.504	0.541	0.546

t statistics in parentheses
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

model performance. The results of the F-tests for joint significance of county, year and month are found in Appendix A.2. The Ordinary Least Squares (OLS) regression, which includes time and county fixed effects, is concluded to be the most significant linear model. Besides controlling for observable heterogeneity over time and space, year and month variables are used to identify and correct for autocorrelation.

The linear regression is statistically significant; the R-squared value is 0.722 and nine statistically significant coefficients are estimated. Significant p-values and t-statistics indicate that several independent variables influence the dependent variable, *Sale Price*. Furthermore, the coefficients of the significant variables conform to intuition. Land class variables exhibit positive relationships with *Sale Price* whereas *Town Distance* exhibits a negative relationship; coefficient magnitudes also conform to economic intuition. The estimation of variables which conform to economic theory indicate that the linear model is significant in explaining the implicit value of irrigation water in the CBP region but the precision of the OLS model is questioned. The OLS model is performed assuming the Gauss-Markov theorem is satisfied. The Gauss-Markov theorem states that OLS is the best linear unbiased estimator (BLUE) if; errors are uncorrelated, errors have an expectation of zero and errors have equal variance. The linear model's mean square error, large standard errors and large confidence intervals indicate that one or more of Gauss-Markov assumptions are violated and thus OLS is not optimal.

Suspecting that residential and commercial markets have a large influence on model estimates, I calculate several discrepancy, leverage and influence statistics. Discrepancy is a measurement of the difference between the predicted variable estimate and the observed variable estimate. Measures of leverage indicate an observation's deviation from the mean. Discrepancy and leverage alone do not indicate extraordinary observations; influence is determined through the calculation of DFBETAs[10] and Cook's distance.[11] Three observations

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[10] DFBETAs are used to indicate influence. DFBETAs measure the difference between the calculated regression coefficients when all observations are included versus when one observation is deleted.

[11] Cook's distance is another statistical tool used to detect influence. Cook's distance indicates the distance an estimation moves within a confidence ellipsoid of parameter values when an observation is deleted.

appear through-out DFBETA's, Cook's distance, Student's residuals[12] (discrepancy measure) and leverage measurements. Examination of the suspect observations indicate that influential observations are located in Grant County and each observation has abnormally large acreage, sales price and improvement values. Influential observations are not dropped because these observations are important representations of high-valued and large-acreage cropland, a facet of the land market which otherwise is not captured in this model. Results of discrepancy, leverage and influence measures can be found in Appendix A.4.

Biased errors in the linear model are suspected to be attributed to one of two statistical issues; autocorrelation or heteroskedasticity. Autocorrelation is the correlation of observation errors across time. Heteroskedasticity is the correlation of errors between independent variables. When autocorrelation and heteroskedasticity exist, the model is not minimum variance although it is still unbiased. Large standard errors and biased t-statistics are indicative of variance that is not minimized. Examination of *Sale Price* plotted on *Month* and the insignificance of all but one month indicates that autocorrelation is likely not an issue. This is supported by the short time-horizon and relatively stable economic conditions of Washington State between the years of 2014 and 2017. Suspecting heteroskedasticity, residuals are plotted and displayed in Figure 4.1.

A Breusch-Pagan test for heteroskedasticity is preformed on the regression as a whole and on each condition separately. The linear model tests significant and thus positive for heteroskedasticity. Examination of the Breusch-Pagan test for each condition indicates correlation between errors in all of the independent variables except *Canal Distance* and *Town Distance*. An examination of the added variable plots[13] provides insight into error correlation derived from the skewed and non-negative nature of the independent variables. An investigation of the model's kernel density plots[14] for each variable confirm this. Economic

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[12] Student's residuals are used to measure discrepancy. To obtain Student's residuals, a regression's residuals are divided by an estimate of standard deviation.

[13] Added variable plots, also known as partial regression plots, show the effect of adding an additional variable to a multi-variable regression. Such plots are often used to indicate high leverage data observations.

[14] Kernel density plots are used to visualize the density of continuous random variables and to estimate the conditional expectation of a variable.

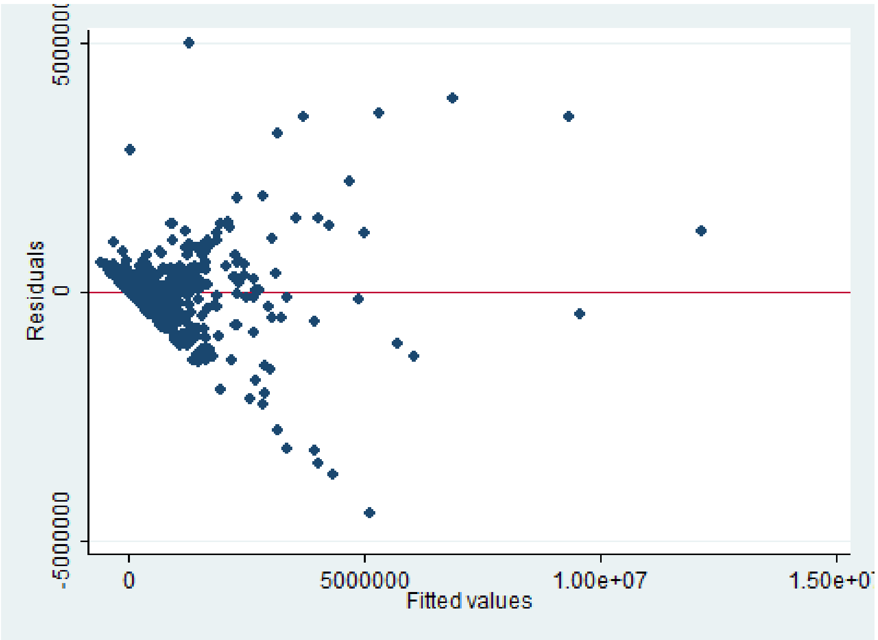

Figure 4.1: Linear Model Residuals

theory suggests a log-linear (Poisson) model to correct for non-negative, skewed distribution. Before confirming a log-linear model, several alternative transformations are investigated.

4.3 Log-Linear Model

Many hedonic valuation models rely on the Box-Cox transformation[15] to normalize the distribution of non-linear dependent variables. Seeing as the distribution of several dependent variables in this data set is not normal, testing using the Box-Cox transformation allows for the specification of functional form such that data are normalized. A classic Box-Cox transformation (dependent variable only) is tested; this semi-logged Box-Cox transformation indicates the significance of the linear, log-linear and square-root forms. Transformation and testing of logged right-hand side variables is unreliable; transforming does not normalize the distribution of values of zero since the transformation for zero is log(0). Dependent variables

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[15] The Box-Cox transformation applies an estimate of a power transformation parameter, usually the maximum likelihood estimation, to a given data set (Box and Cox, 1964). A Box-Cox transformation is used to transform the distribution of non-normal data into a normal distribution such that Gauss-Markov assumptions hold.

in this model contain large populations of zeros thus dependent variables are not logged. Transformations of the linear independent variables are performed on both the logged dependent variable and square-root dependent variable. The square-root form of the dependent variable does little to increase the model's significance and the square-root form of the independent variables decreases the significance of the model. Thus, a log-linear transformation is chosen. Summarized results of the log-linear model with and without fixed effects is found in Table 4.3. Full estimates including county, year and insignificant variables are found in Appendix A.3.

As in the linear model, fixed effects are found to be important in determining the influence of the dependent variables in the log-linear model. F-test's for joint hypotheses confirm the significance of year, month and county fixed effects; the results of these tests can be found in Appendix A.3. The log-linear model, which includes time and county fixed effects, is herein referred to as "the log-linear model."

To determine if the log-linear model is representative of the data set, *Sale Price* distribution is plotted for the linear and log-linear models. Histograms of price before and after logging are displayed in Figure 4.2 and Figure 4.3.

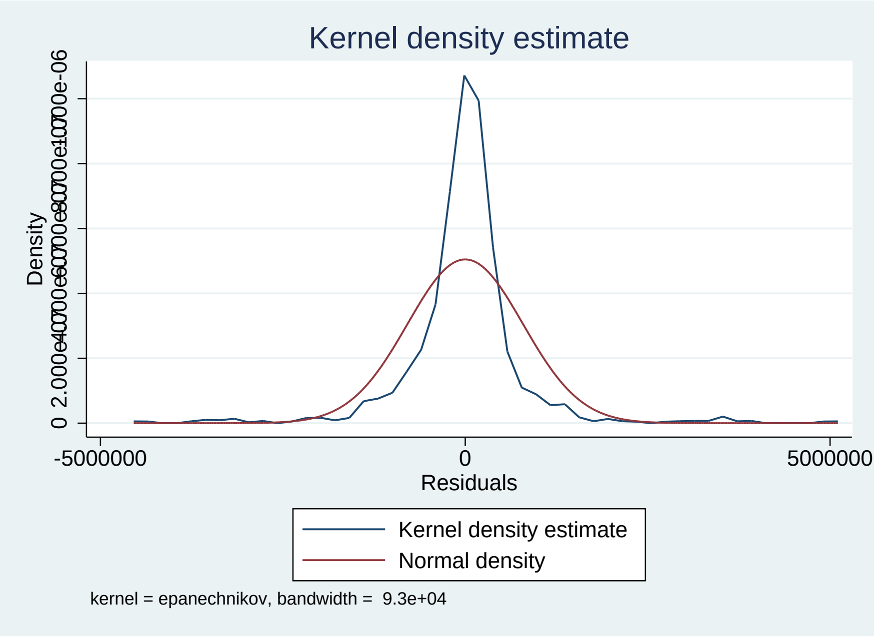

Figure 4.2: Skewed Distribution of the Linear Dependent Variable

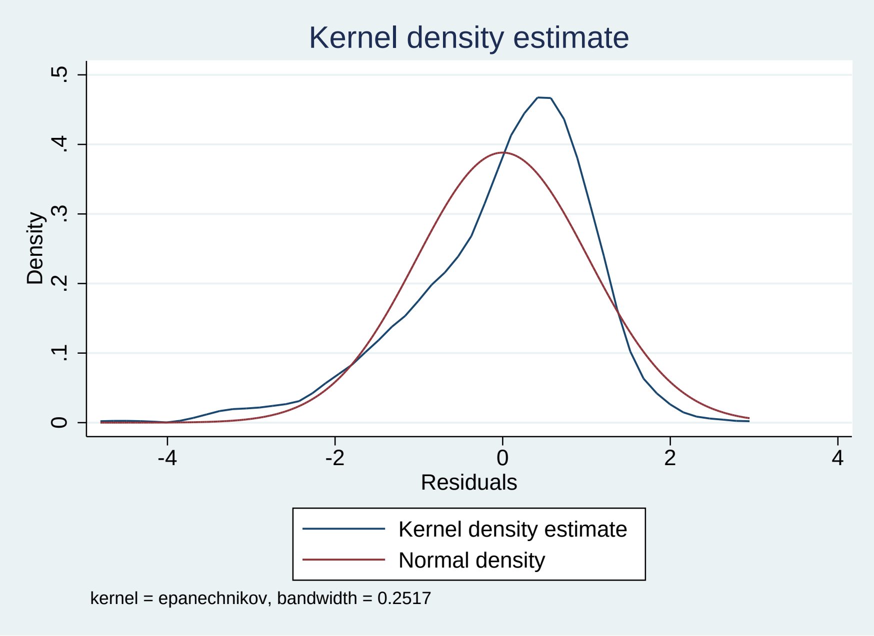

Figure 4.3: Results of a Logged Dependent Variable

The kernel density plots indicate that logging *Sale Price* normalizes the distribution of the data set and allows for the estimation of a model which conforms to Gauss-Markov assumptions. The residuals of the log-linear model are examined in order to determine if variance is minimized. The log-linear residuals are displayed in Figure 4.4, these residuals indicate a decrease in heteroskedasticity.

Figure 4.4 indicates that logging *Sale Price* decreases error variance. To confirm a decrease in heteroskedasticity, a Breusch-Pagan test is performed. The Breusch-Pagan test measures correlation between dependent variable errors. The Breusch-Pagan test for the log-linear model has a Chi-Square value of 0.64 and p-value of 0.43 indicating that heteroskedasticity is no longer a significant issue. Rejection of error correlation indicates efficiency; the log-linear model conforms to Gauss-Markov assumptions and the model is unbiased and efficient unlike the linear model. The mean square error, confidence intervals and standard errors of the log-linear model support the use of a log-linear model. The mean square error adjusts from 8.2e+05 in the linear model to 1.05 in the log-linear model. The log-linear model displays less variance than the linear model and errors are not correlated.

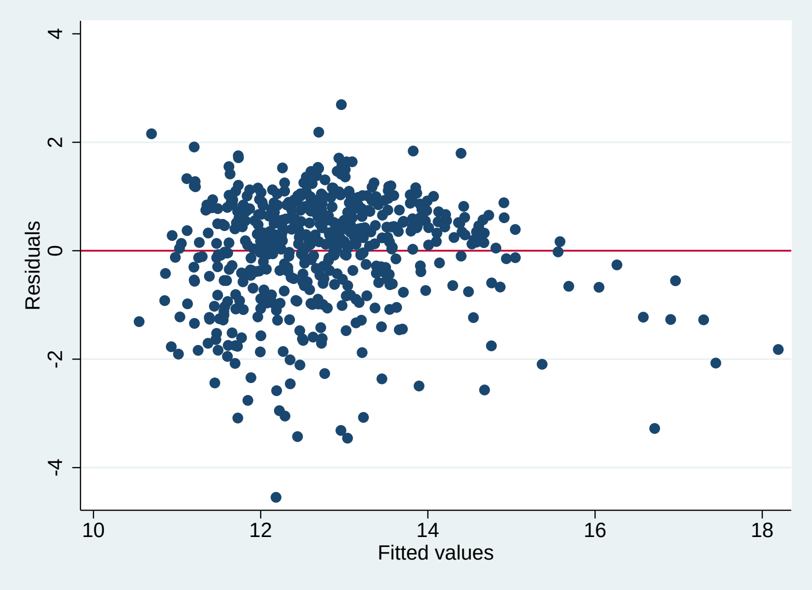

Figure 4.4: Density Plot of Residuals of the Log-Linear Model

Several alternative functional forms are considered but eventually dismissed. A weighted least squares model (WLS)[16] is tested using the means of several land class variables. The presence of multiple heteroskedastic independent variables results in ineffective WLS models. Truncation of error terms[17] is considered but not acted upon; all observations in the data set are considered relevant. Maureen L. and McConnell (1988) find that when proxies or omitted variables are present, simple models such as linear and log-linear models perform better than models containing complicated functional forms. The reduction in heteroskedasticity and increase in the significance of the logged dependent variable indicates that a log-linear regression is the best fit for this data set.

The implicit value of irrigation water and the influence of water security is estimated using the model displayed in Equation 4.2:

$$Log(Y_{it}) = \beta_0 + \beta_i X_{it} + C_i + T_t + \varepsilon_{it} \tag{4.2}$$

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[16] Weighted least squares is used when heteroskedasticity violates OLS assumptions. A model's best fit is found through the minimization of the sum, of all observations, of the squared distance between an observation and the regression line.

[17] Truncated regression models are used when errors are not normally, independently, and identically distributed. Observations above or below a given threshold are excluded and statistically corrected for which allows for consistent and unbiased estimates of coefficients.

Y_{it} represents the logged sale price of parcel i in county C during time t, β_0 is the model constant, C_i is a vector of county fixed effects and T_t is a vector of year and month fixed effects. X_{it} is composed of the same variables used in the linear regression and corresponding β_i's represent variable estimates. ε_{it} is the error term correlated within county and time but not across county and time. Attributes in the log-linear regression consist of the productive component, consumptive component, spacial component and water component variables as well as two interaction terms and fixed effects.

Sale Price is logged, the independent variables are linear and the Huber-White robust standard errors[18] approach is used to produce heteroskedasticity-consistent random errors. The final model displays a minimal amount of heteroskedasticity and a minimal amount of autocorrelation. Multicollinearity is checked through the computation of variance inflation factors[19] and correlation matrices.[20] Omitted variables were tested for using the Ramsey regression specification error test[21] for omitted variables. The model tested slightly positive for omitted variables. Variables which represent the full influence of commercial and suburban markets on agricultural land are suspected to be omitted from this model. No additional variables are added due to data availability and the conformity of this model to previous literature. The Wald test[22] is used to confirm the inclusion of all variables in the log-linear model. The full results of the log-linear model, including fixed effects, is found in Appendix A.7.

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[18] The Huber-White robust standard errors approach, also known as heteroskedasticity consistent standard errors approach, allows for the fitting of a model which contains heteroskedastic errors. The Huber-White standard errors correct for biased OLS estimates when the variance of error terms is greater than a given observation's variance.

[19] Variance inflation factors (VIFs) estimate changes in variance due to correlation between variables; A VIF is an index used to measure multicollinearity.

[20] A correlation matrix indicates the level of correlation between independent variables. All independent variables are measured against each other; a ratio of one indicates perfect collinearity.

[21] The Ramsey regression specification error test is used to test whether omitted variables are biasing a model. Acceptance of the null hypothesis indicates that endogeneity is present and thus coefficient estimates are biased.

[22] The Wald test is used to determine the significance of including a given variable in a regression. The Wald test is a hypothesis test which estimates a given variable's true value based on a sample estimate.

Chapter 5

Results

5.1 Results of the Log-Linear Regression

This hedonic analysis of land values in Grant County, Franklin County and Adams County provides an estimate of the implicit value of irrigation water, differentiated by water source, in the CBP region. Besides providing insight into the added value of various water attributes, this study estimates the influence of several land characteristics. Using a log-linear functional form as well as time and county fixed effects, agricultural parcel sale prices are regressed on twenty-one explanatory variables. Five variables are found to significantly influence agricultural land sale price at the 0.1 percent level, six variables at the 1 percent level and six variables at the 5 percent level. The model explains 54 percent of the variation in the data set while the variance of the model's residual is 1.05. Variance is minimized (note standard error terms in Table 5.1) indicating that Gauss-Markov assumptions are achieved. Given the complexity of agricultural land markets, the log-linear model provides a representative estimation of the influence of irrigation water, differentiated by water security, on agricultural land values in the CBP region. The final model is shown in Table 5.1.

The implicit value of irrigation is estimated and represented by *Irrigated* in Table 5.1; the contribution of other land class variables, improvement values and permanent crop values are also found in Table 5.1. All productive, consumptive, spacial and water component variables are significant except for *Improvement Value*, *Other*, *Pasture* and *In Odessa*. The magnitude and signs of coefficients conform to hypotheses indicating that the log-linear model represents the influence of land characteristics on agricultural land values in the CBP region. To assess the magnitude of irrigation water's influence, water attribute estimates as well as other significant variables are discussed. Coefficients of continuous variables are

Table 5.1: Regression Results for the Log-Linear Regression

Variable	**Coefficient**	**T-Statistic**	**Std. Error**
Logged Sale Price			
Year			
Year=2015	-0.144	(-0.90)	0.161
Year=2016	0.326*	(2.00)	0.163
Year=2017	0.425*	(2.13)	0.199
County			
County=Franklin	-0.159	(-1.09)	0.147
County=Adams	-0.331*	(-2.04)	0.162
Productive Component			
Improvement Value	-0.000000149	(-1.05)	-0.000000142
Permanent Crop Value	0.000000605*	(2.23)	0.000000271
Irrigated	0.00492***	(6.63)	0.00074
Dryland	0.000846***	(6.48)	0.00013
Homesite	0.0343*	(2.50)	0.0137
NonCrop	0.000466**	(2.99)	0.00016
Other	-0.0168	(-1.54)	0.0109
Pasture	0.000754	(1.93)	0.00039
Water Component			
In CBP	0.512**	(1.69)	0.180
In Odessa	0.307	(2.83)	0.180
Well Depth	0.00084**	(2.75)	0.0003
Consumptive component			
Commercial Zone	1.702**	(2.63)	0.647
Suburban Zone	-0.395**	(-2.81)	0.140
Other Zone	-0.436*	(-1.69)	0.258
Spatial Component			
Canal Distance	0.0283***	(4.04)	0.007
Town Distance	-0.0114*	(-1.45)	0.149
Interactions			
*Irr*WellDepth*	-0.00000276**	(-2.66)	0.00000104
*Irr*InCBP*	0.00477***	(4.65)	0.0010
Constant	11.59***	(36.24)	0.319
Observations	516		
R^2	0.546		

t- statistics in parentheses
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

interpreted as the marginal willingness to pay for that characteristic. Since the model is log-linear, the coefficients are interpreted as “a one-unit change in the independent variable results in a percent change in the dependent variable.”

5.2 Interpreting the Influence of Irrigation Water and Irrigation Water Security on Land Value

A one-acre increase in irrigated acreage in the CBP region results in a 0.97 percent increase in the land sale price whereas a one-acre increase in dryland acreage results in a 0.08 percent increase in the sale price. Given the average transaction sale price, $868,564, a one-acre increase in irrigated production increases the sale price of agricultural land by $8,433.76. This is opposed to a one-acre increase in dryland production which increases the sale price of agricultural land by $734.81. The premium created by the presence of irrigation water is $7,698.95, this premium is not surprising given the economic value of irrigated crops and agricultural processing in the CBP region. Estimates of CBP land values conform to NASS' (2016) study which finds the average value of irrigated cropland is roughly six-times the average value of non-irrigated cropland in Washington State. Reliance on irrigated agriculture in the CBP region likely increases the disparity between land values in the data set such that the added value of irrigated cropland is nearly eleven-times the added value of non-irrigated cropland.

Despite the positive influence of irrigation on CBP region agricultural land, producers are opting to produce via dryland. Water insecurity results in decreases in the reliability of water delivery and water quality; water insecurity causes increases in dryland production. In order to estimate the influence of water security, *In CBP* and *Irr*InCBP* are estimated. Location, which is a proxy for water security, plays a large role in determining agricultural land values. To determine if a premium is derived from secure surface water rights, *Irrigated* is interacted with *In CBP* and is represented by *Irr*InCBP*. Secure surface water irrigation located in the developed portion of the CBP is found to be significant. 0.48 percent of CBP land premiums are explained by secure surface water. The significance of surface water premiums indicates that some of the agricultural land value heterogeneity between the CBP region and Odessa Subarea is derived from water security. *Irr*InCBP* provides insight into the implicit value of secure surface water; CBP surface water rights exhibit a premium which increases the implicit value of irrigation.

In order to provide insight into the implicit value of groundwater, *Well Depth* and *Irr*WellDepth* are estimated. *Well Depth* indicates the presence of groundwater; it is found that a one-foot increase in the depth of a well increases land sale price by 0.084 percent. As expected, irrigation derived from groundwater positively impacts the sale price of agricultural land but the added value of groundwater irrigation is less than the added value of surface water irrigation (0.48 percent). Furthermore, when the implicit value of groundwater irrigation is measured, taking well depth into account, it is found that the value added by groundwater irrigation decreases with well depth. The value added by an increase in one-acre of groundwater irrigated land decreases by 0.00028 percent per-foot of well depth. The use of groundwater for irrigation exhibits a premium, positively increasing agricultural land sale price, but every additional foot of well depth exhibits a cost which decreases this premium. Agricultural land which is irrigated using groundwater is decreasing in value as well depth increases.

Groundwater use in the Odessa Subarea devalues agricultural land whereas CBP surface water use increases the value of agricultural land. Given an average CBP region transaction, \$868,564, irrigation exhibits a \$7,698.95 premium; \$3,416.93 of this premium is derived from secure surface water. Secure surface water rights increase the implicit value of irrigation in the CBP. Insecure groundwater rights also increase the implicit value of irrigation in the CBP region but the value added by groundwater decreases as well depth increases. It is found that the premium added by groundwater irrigation decreases in added value at a rate of \$2.40 per foot of well depth. Considering that the average well in the Odessa Subarea is 800 to 1,000 feet deep, well depth significantly decreases groundwater irrigation premiums. As well depth increases, the implicit value of groundwater irrigation decreases. Groundwater irrigated agricultural land in the Odessa Subarea is being devalued as well depth increases.

In the CBP region, historical irrigation water allotments range from 3 acre-feet per year to 4 acre-feet per year (Svendsen and Vermillion, 1994). Increases in technology and productivity have decreased per-acre water consumption; allotments ranging from 2.5 acre-feet per year to 3 acre-feet per year are now used to grow high-valued crops throughout the developed and undeveloped portions of the CBP. On average, 2.5 acre-feet per year is sufficient in growing potatoes in Eastern Washington. Potato production is one of the highest-valued crops grown in both the developed CBP region and Odessa Subarea, an allotment of 2.5 acre-feet per year is assumed when determining the added value of one acre-foot of water (delivered annually). The added value of one acre-foot of irrigation water in the CBP region is \$3,079.58. Nearly half of this added value is derived from surface water; the added value of one acre-foot of surface water in the CBP region is \$1,366.77. The premium created by one acre-foot of irrigation nearly doubles when irrigation allotments are derived from secure surface water. Quantification of irrigation premiums, per acre-foot, provide insight into the marginal value added to CBP cropland sale prices. Such premiums can be used to determine the value of irrigation water, derive producers willingness to pay and set irrigation water prices.

The implicit value of other significant variables provides insight into the influence of irrigation water in the CBP. As expected, *Homesite* is found to have the greatest influence on land values followed by *Irrigated*. A one-acre increase in a parcel containing a place of residence results in a 3.49 percent increase in land sale price. The large influence of *Homesite* follows economic theory, the presence of a residence represents long-run investments and additional amenities beyond agricultural production. The significance and large magnitude of the *Homesite* coefficient indicates the importance of including this variable in agricultural land value estimations. The existence of permanent crops is found to be highly significant but the coefficient of estimation is converging on zero. The small magnitude of the *Permanent Crop Value* coefficient is likely derived from the small data set sample size. The model indicates that permanent crop production influences land values but the magnitude of this influence is unknown.

The two variables indicating whether a parcel is zoned for commercial or suburban use are significant at the 5 percent level whereas the variable indicating other zoning designations is significant at the 10 percent level. Both suburban and other zoning classifications negatively influence the sale price, while commercial zoning positively influences agricultural land sale price. Interpretation of these coefficients is not straightforward. Suburban zoning represents relatively small, unimproved plots of land that are a primary place of residence. Commercial zoning represents land zoned for future commercial use or land that is used for agricultural storage and processing. It is not surprising that *Commercial Zone* positively influence *Sale Price* seeing as commercially zoned land often contains long-run investments such as infrastructure. *Suburban Zone* and *Other Zone* negatively influence *Sale Price*. I hypothesize that this negative relationship is due to agricultural land value in the CBP region. Agricultural land values in rural areas, such as the CBP region, are likely greater than suburban land value or undeveloped land value.

The influence of the model's spatial variables, distance to town and canal distance, are ambiguous. As the distance to the closest town increases, the land sale price decreases. This is not surprising given the extensive literature on the relationship between land value and urban-derived amenities. *Town Distance*'s relationship is opposed to *Canal Distance*'s relationship with *Sale Price*; as distance from the East Low Canal increases, agricultural land value increases. While surprising at first, an examination of the data and county maps gives insight into *Canal Distance*'s positive relationship. The land which lies between the East Low Canal and groundwater irrigated ground in the Odessa Subarea is largely under dryland production. This means that agricultural land near the East Low Canal is worth less than cropland far from the East Low Canal. Thus, *Canal Distance* is not measuring the true influence of irrigation water infrastructure but instead the spatial layout of production in the region. While a better proxy must be found to measure infrastructure influence on the implicit value of water, *Canal Distance* is used in this model because the estimate is highly significance and correlated with *Town Distance*.

Chapter 6

Conclusion

In this thesis, a hedonic analysis is used to estimate the value of irrigation water and irrigation water security in the CBP region. This model provides estimates of irrigation water premiums, differentiated by water security, and the value added by irrigation water per acre-foot. The quantification of the value of irrigation water, per acre-foot, can be used to better understand regional water pricing. Water pricing which reflects the added value of irrigation can be used to develop efficient water markets in the CBP region. Water pricing models are derived from water values; conflicts in the CBP region stem from miscalculations of the implicit value of irrigation water. Several studies have estimated the market value of irrigation expansion in the CBP region; estimates of market value serve as proxies for the implicit value of water. Although the implicit value of irrigation water in the CBP region is contentious, estimated values are used to develop water pricing schemes which justify The Modified Partial Replacement Plan (U.S. Bureau of Reclamation, 2012). Water values are believed to over-estimate irrigation water benefits and misrepresent the economic impacts of groundwater depletion (Whittlesey and Butcher, 2012; Columbia-Snake River Irrigators Association, 2012). Understanding the added value of irrigation water, per acre-foot, can be used to model water pricing schemes and set permit prices. A hedonic analysis of CBP agricultural land values allows for the estimation of the implicit value of irrigation water in order to increase knowledge regarding water pricing in the CBP region.

Results provide insight into the implicit value of irrigation water, the influence of CBP surface water rights and the negative impacts of groundwater use. I find that some of the disparity in CBP region agricultural land values is derived from irrigation; while irrigation exhibits a premium which increases land value, well depth decreases the value added by irrigation premiums. The average premium created by an acre-foot of irrigation water in the CBP region is $3,079.58. Surface water adds $1,366.77 to the premium created by an acre-foot of irrigation water. This is opposed to groundwater which decreases irrigation water premiums by $2.40 per-foot of well depth. Results shed light on the influence of secure surface water rights on agricultural land values and the costs of groundwater depletion.

Estimates of the per acre-foot added value of irrigation water, differentiated by water security, allows for accurate benefit-cost analyses and the quantification of water permit prices. Accurate water prices not only promote irrigation efficiency within agriculture but also the management of water as a limited resource (Wichelns, 2010). The premium created by irrigation, particularly secure surface water irrigation, should be considered when deriving the benefits of irrigation infrastructure expansion. Hedonic estimates of water value do not capture the full market impacts of irrigation in the CBP region. Irrigation and irrigation water security influence cropping decisions, drive long-run investments and have lasting impacts on both processors and municipalities in the region. While a hedonic analysis does not provide insight into the full value derived from irrigation, hedonic analyses estimates can be used in production models to determine irrigation benefits beyond pure water value.

The cost of groundwater depletion, per-foot of well depth, is not quantified by current CBP region benefit-cost analyses. This study estimates the decreasing value of groundwater premiums; well depth estimates can be used in production models to derive to the costs of continued groundwater use and calculate the costs of stalled infrastructure expansion. Furthermore, understanding the implicit value of irrigation water allows for an understanding of CBP producers willingness to pay; permit prices should reflect producer's willingness to pay. If permit prices do not reflect producer's willingness to pay, incentives to overuse or under use surface water will result in misallocation of water, losses of high-valued crop production and continued groundwater depletion. Estimates of the added value of irrigation water in the CBP region allows for a proper quantification of permit prices, understanding of groundwater costs and the determination of the benefits of surface water use.

Water security influences crop production; surface water use guarantees irrigation water in water-short years whereas groundwater use is not reliable due to low water quality and low water availability. Cropping choices are based on both water availability and water security in the CBP region. Access to secure irrigation water allows producers in the developed CBP region to grow permanent crops such as apples, cherries, pears and grapes. Permanent crop production is of greater value than non-permanent crop production. Non-permanent crops such as potatoes, onions and corn are grown in both the developed portion of the CBP region and the Odessa Subarea. While irrigation allows for the production of non-permanent crops in the Odessa Subarea, groundwater concerns mitigate the production of permanent crops. Groundwater use is accompanied by water quality and quantity concerns including increased water-temperature, element build-up and salinity. As production costs rise, due to the implications of groundwater use, producers are finding it more feasible to produce via dryland. Access to secure irrigation water tends to increase the revenue generated through the production of high-valued crops whereas groundwater use decreases this revenue. The loss of high-valued crop production in the CBP region is decreasing the value of the CBP region agricultural industry, in effect negatively impacting the regional economy.

Several limitations exist in this model. Limitations can be addressed in future investigations in order to improve estimates of water value such that water pricing in the CBP region can be better quantified. For obvious reasons, an increase in the quality of water data can add value to this investigation pertaining to water values. The inability of governing entities to fully record and quantify water source and use creates ambiguity in water value. Advances in technology and information lead to increased availability of water information; this will be essential as water becomes more scarce. An increase in sample size through the addition of Lincoln County data will add depth to the study. An increase in the data set sample size has the potential to mitigate bias derived from the estimation of multiple markets. The small sample size of several attributes is believed to misrepresent the contribution of the consumptive component and the impacts of commercial and suburban zoning. Soil quality data can further validate irrigation water values by providing parcel-based characteristics. Soil is often used as a variable in hedonic land valuations; the absence of soil data in this model of the CBP region likely contributes to omitted variable bias. Improvements to heteroskadastic errors can be made through the exploration of more intensive econometric methods following the work of Xu et al. (1993), Coelli et al. (1991) and Faux and Perry (1999). This being said, complicated functional forms do not necessarily provide a better representation of land sales (Maureen L. and McConnell, 1988). Further examination of market structures and functional form can allow this model to overcome general concerns pertaining to hedonic analyses.

This model provides an estimation of the implicit value of irrigation water and the influence of irrigation water security on CBP region agricultural land values. Water value estimates can be used in future investigations pertaining to water pricing and irrigated infrastructure development. Wichelns (2010) finds that water value estimates can be used to reflect the scarcity value of water in order to mitigate misuse of water and to develop accurate water prices such that infrastructure costs are recovered through efficient water allocation. Understanding the contribution of water in the CBP region gives insight into the loss of high-valued irrigated cropland in the Odessa Subarea and provides knowledge regarding the potential impacts of irrigating via groundwater. Through a better understanding of irrigation water value, efficient water pricing schemes can be developed which promote irrigation water allocation efficiency, mitigate groundwater depletion and encourage high-valued crop production in the CBP region.

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Appendix A.1: Agriculture in Washington State

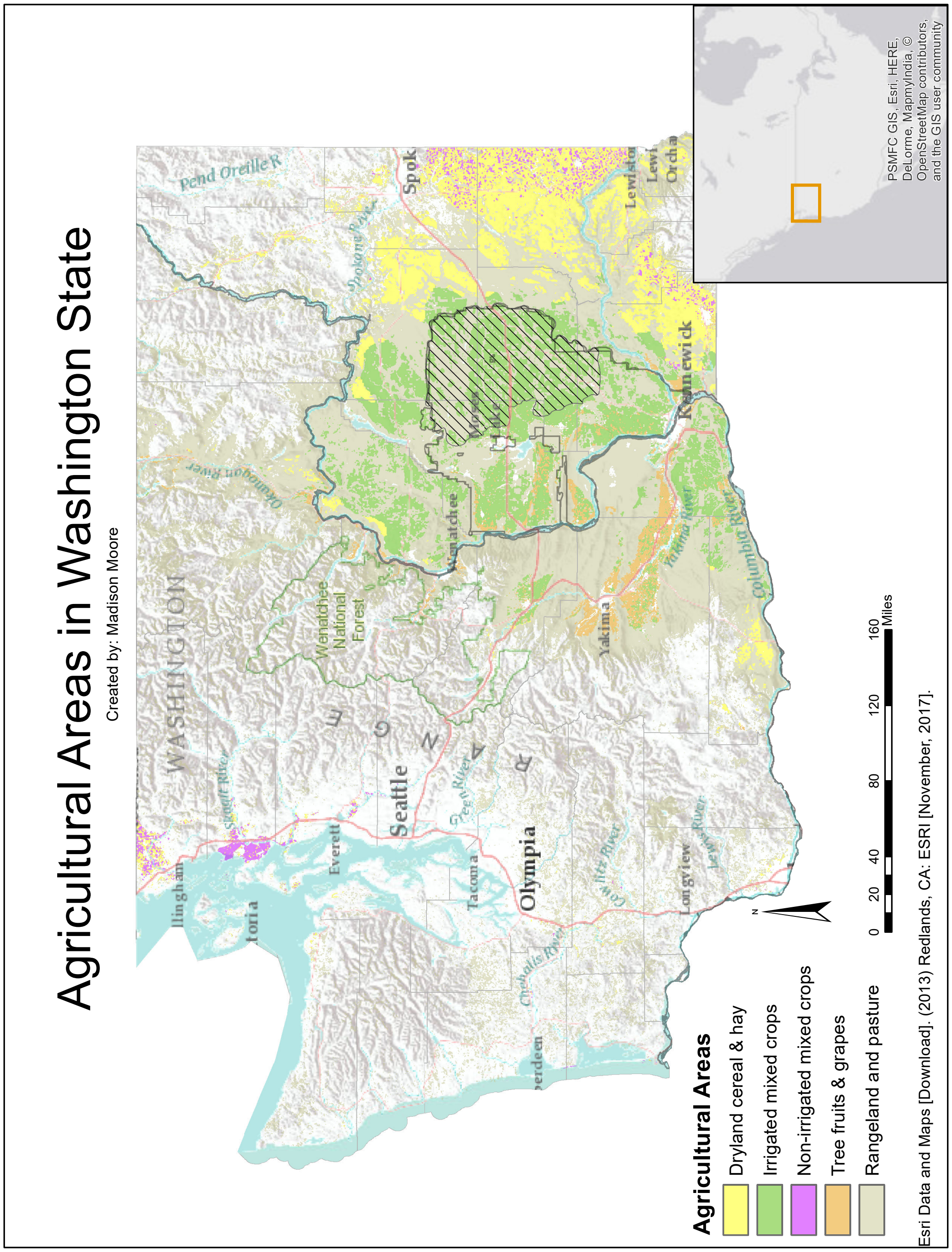

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Figure 6.1: Agricultural Areas in Washington State

Appendix A.2: Linear Model With and Without Fixed Effects: Full Results

Table 6.1: Linear Regression With and Without Fixed Effects (FE)

Variable	**No FE**	**Time FE**	**Time & County FE**
Sale Price			
Year=2015		-55365.40	-69344.74
		(-0.44)	(-0.55)
Year=2016		227991.70	197550.60
		(1.78)	(1.55)
Year=2017		287439.30	243980.70
		(1.84)	(1.56)
Month=2		117756.80	106603.80
		(0.59)	(0.54)
Month=3		32960.60	26755.51
		(0.18)	(0.15)
Month=4		10486.47	7007.257
		(0.05)	(0.04)
Month=5		-45918.05	-70573.78
		(-0.24)	(-0.37)
Month=6		50155.63	32627.31
		(0.26)	(0.17)
Month=7		314865.80	343240.50
		(1.55)	(1.71)
Month=8		172164.80	198415.50
		(0.80)	(0.92)
Month=9		332057.40	311352.60
		(1.61)	(1.51)
Month=10		171934.60	187115.80
		(0.85)	(0.93)
Month=11		65877.68	37288.82
		(0.34)	(0.19)
Month=12		142795.80	122298.50
		(0.80)	(0.68)
County=Franklin			-150028.90
			(-1.30)
County=Adams			-421846.10***
			(-3.33)
In Odessa	-41621.130	-19517.89	131566.10
	(-0.31)	(-0.15)	(0.93)
In CBP	59601.290	30551.87	19638.36
	(0.42)	(0.21)	(0.14)
Observations	516	516	516
R^2	0.704	0.716	0.722

t- statistics in parentheses
*p $<$ 0.05, **p $<$ 0.01, ***p $<$ 0.001

Table 6.2: Linear Regression With and Without Fixed Effects (FE)

Variable	**No FE**	**Time FE**	**Time & County FE**
Improvement Value	0.284*	0.276*	0.304**
	(2.57)	(2.48)	(2.74)
Permanent Crop Value	1.122***	1.152***	1.146***
	(5.33)	(5.45)	(5.40)
Irrigated	10270.040***	10162.93***	10266.590***
	(17.66)	(17.39)	(17.69)
Dryland	760.068***	765.70***	822.549***
	(7.54)	(7.53)	(8.05)
Homesite	34303.390***	31948.63**	33874.390**
	(3.28)	(3.01)	(3.16)
NonCrop	200.745	208.02	234.042
	(1.67)	(1.70)	(1.92)
Other	-5556.049	-7518.79	-14016.960
	(-0.70)	(-0.93)	(-1.64)
Pasture	321.101	347.03	202.094
	(1.06)	(1.14)	(0.66)
Canal Distance	15580.72**	17168.65**	19049.820***
	(2.88)	(3.13)	(3.47)
Town Distance	-5872.556	-5833.90	-4462.736
	(-0.99)	(-0.96)	(-0.72)
Well Depth	193.669	165.46	138.199
	(0.81)	(0.69)	(0.58)
Commercial Zone	1580216.000**	1327519.00**	1280073.000*
	(3.15)	(2.60)	(2.53)
Suburban Zone	246335.200*	218732.60	88306.580
	(2.47)	(2.15)	(0.80)
Other Zone	137565.200	146815.00	71914.920
	(0.69)	(0.73)	(0.41)
*Irr*WellDepth*	-2.269*	-2.11*	-2.114**
	(-2.78)	(-2.57)	(-2.60)
*Irr*InCBP*	-534.765	-333.34	-198.219
	(-0.68)	(-0.41)	(-0.25)
Constant	-195023.900 *	-426104.100*	-346003.000
	(-1.17)	(-1.70)	(-1.38)
Observations	516	516	516
R^2	0.704	0.716	0.722

t- statistics in parentheses
*p < 0.05, **p < 0.01, ***p < 0.001

F-test for Joint Hypothesis (Linear)

Command: test (2.county=0) (3.county=0)

```
F( 2, 481) = 5.67
Prob > F = 0.0037
```

Command: test (2015.year =0) (2016.year =0) (2017.year =0)

```
F( 3, 481) = 3.77
Prob > F = 0.0107
```

Command: test (2.month =0) (3.month =0) (4.month =0) (5.month =0)(6.month =0)(7.month =0)(8.month =0)(9.month =0)(10.month =0)(11.month =0)(12.month =0)

```
F( 11, 481) = 0.81
Prob > F = 0.6272
```

Appendix A.3: Log-Linear Model With and Without Fixed: Effects Full Results

Table 6.3: Log-Linear Regression With and Without Fixed Effects (FE)

Variable	**No FE**	**Time FE**	**Time & County FE**
Logged Sale Price			
Year=2015		-.137	-0.144
		(-0.86)	(-0.90)
Year=2016		0.345*	0.326*
		(2.13)	(2.00)
Year=2017		0.454*	0.425*
		(2.29)	(2.13)
Month=2		-0.245	-0.251
		(-0.97)	(-0.99)
Month=3		-0.337	-0.341
		(-1.46)	(-1.48)
Month=4		-0.371	-0.368
		(-1.50)	(-1.49)
Month=5		-0.124	-0.139
		(-0.51)	(-0.57)
Month=6		-0.509*	-0.518*
		(-2.11)	(-2.15)
Month=7		-0.248	-0.228
		(-0.97)	(-0.89)
Month=8		-0.549*	-0.519
		(-0.97)	(-1.89)
Month=9		0.227	0.219
		(0.87)	(0.83)
Month=10		0.109	0.124
		(0.43)	(0.84)
Month=11		-0.0988	-0.115
		(-0.40)	(-0.46)
Month=12		0.0289	0.0385
		(0.13)	(0.17)
County=Franklin			-0.159
			(-1.09)
County=Adams			-0.331*
			(-2.04)
In Odessa	0.322	0.194*	0.307*
	(0.77)	(1.14)	(1.69)
In CBP	0.552**	0.521**	0.512**
	(3.00)	(2.88)	(2.83)
Observations	516	516	516
R^2	0.504 0.541	0.546	

t- statistics in parentheses
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 6.4: Log-Linear Regression With and Without Fixed Effects (FE)

Variable	**No FE**	**Time FE**	**Time & County FE**
Improvement Value	-0.000000119	-0.000000176	-0.000000149
	(-0.83)	(-1.22)	(-1.05)
Permanent Crop Value	0.000000724**	0.000000718**	0.000000605*
	(2.66)	(2.64)	(2.23)
Irrigated	0.00510***	0.00483***	0.00492***
	(6.78)	(6.51)	(6.63)
Dryland	0.000893***	0.000800***	0.000846***
	(6.16)	(6.20)	(6.48)
Homesite	0.0360**	0.0320*	0.0343*
	(2.66)	(2.38)	(2.50)
NonCrop	0.000354*	0.00044**	0.000466**
	(2.27)	(2.85)	(2.99)
Other	-0.00637	-0.0107	-0.0168
	(-0.62)	(-0.05)	(-1.54)
Pasture	0.000852**	0.000864**	0.000754
	(2.18)	(2.23)	(1.93)
Canal Distance	0.0240***	0.0266***	0.0344***
	(3.43)	(3.83)	(4.04)
Town Distance	-0.0097	-0.0119	-0.0193
	(-1.27)	(-1.56)	(-1.45)
Well Depth	0.000893**	0.000867**	0.00118**
	(2.89)	(2.84)	(2.75)
Commercial Zone	1.89**	1.741**	1.702**
	(2.91)	(2.68)	(2.63)
Suburban Zone	-0.304*	-0.282*	-0.395**
	(-2.36)	(-2.19)	(-2.81)
Other Zone	-0.397*	-0.368*	-0.436
	(-1.54)	(-1.44)	(-1.69)
*Irr*WellDepth*	-0.00000284**	-0.00000276**	-0.00000276**
	(-2.68)	(-2.65)	(-2.66)
*Irr*InCBP*	0.00405***	0.00463***	0.00477***
	(3.95)	(4.53)	(4.65)
Constant	11.49***	11.51***	11.59***
	(53.11)	(36.26)	(36.24)
Observations	516	516	516
R^2	0.504	0.541	0.546

t- statistics in parentheses
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

F-test for Joint Hypothesis (Log-Linear)

Command: `test (2.county=0) (3.county=0)`

```
F( 2, 481) = 2.26
Prob > F = 0.1051
```

Command: `test (2015.year =0) (2016.year =0) (2017.year =0)`

```
F( 3, 481) = 7.33
Prob > F = 0.0001
```

Command: `test (2.month =0) (3.month =0) (4.month =0) (5.month =0)(6.month =0)(7.month =0)(8.month =0)(9.month =0)(10.month =0)(11.month =0)(12.month =0)`

```
F( 11, 481) = 1.71
Prob > F = 0.0686
```

Appendix A.4: Linear Model - Discrepancy, Leverage and Influence

Table 6.5: Extremes of *Irrigated* DFBETA's

Obs.	**Cook's Dist.**	**DFBETA's**	**St. Resid.**	**Leverage**	**Excise Num.**
105.	1.13e-07	.0003457	-.0081722	12.87318	227600
366.	4.73e-07	-.0008055	.015201	12.50632	51657
9.	5.05e-07	-.0002983	.0190291	12.90713	231216
176.	9.05e-07	.0002039	-.0284081	12.34235	24899
516.	1.12e-06	-.0002672	.0268919	12.24557	31705
6.	.1125465	.0300986	2.299026	13.82447	231525
529.	.1817343	-.1037629	.7776056	14.31234	30081
69.	.3702891	.1707157	-4.171637	16.71299	228767
302.	.6903076	-4.47354	-1.64557	16.96244	56131
455.	2.305772	-.0943314	-4.294224	11.01652	31212

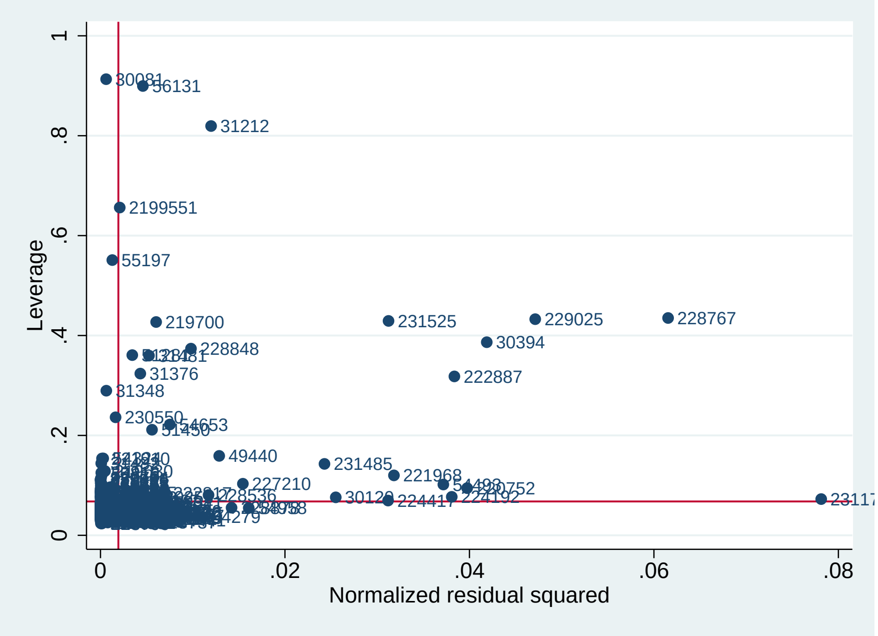

Figure 6.2: Linear Model Leverage

Appendix A.5: Added Variable Plots

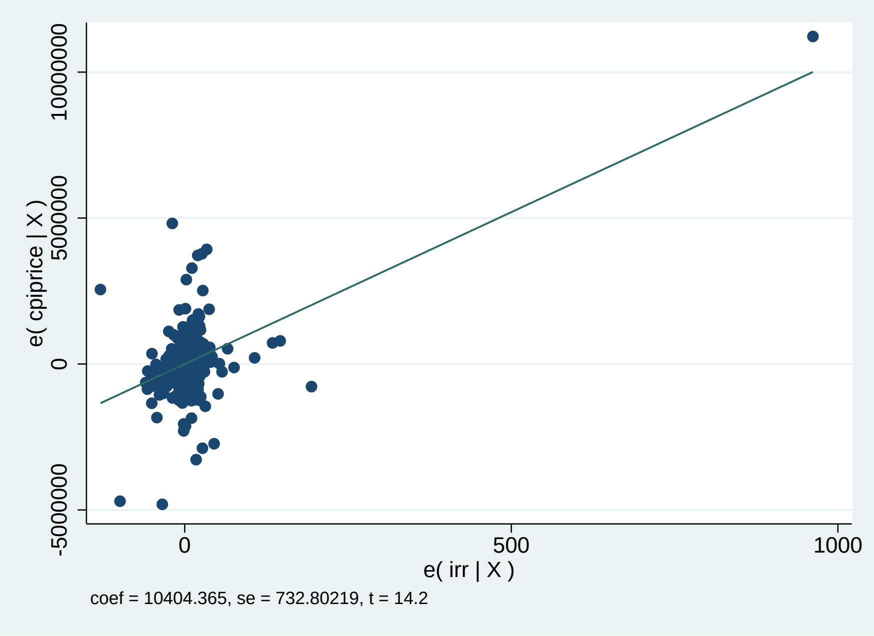

Figure 6.3: *Irrigated* Added Variable Plot

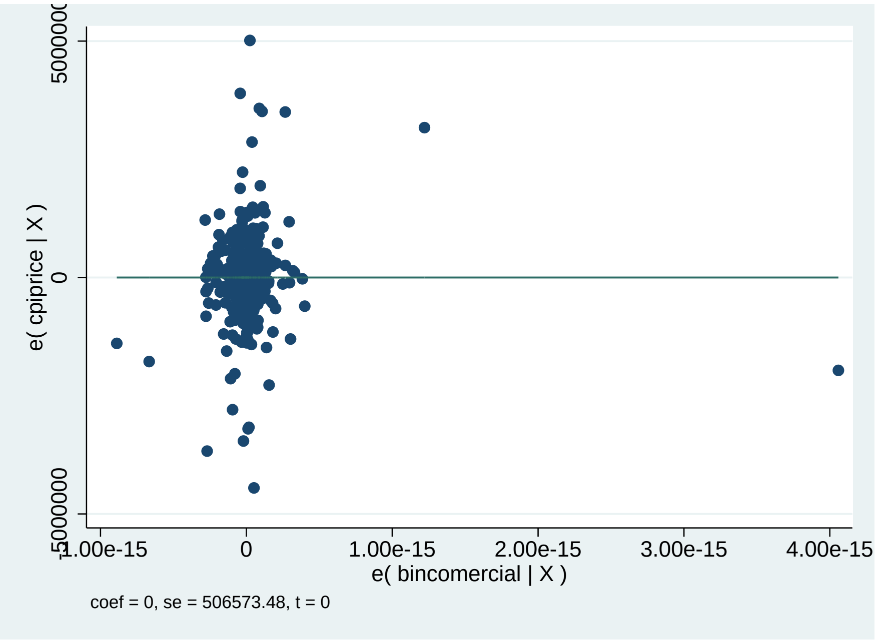

Figure 6.4: *Commercial Zone* Added Variable Plot

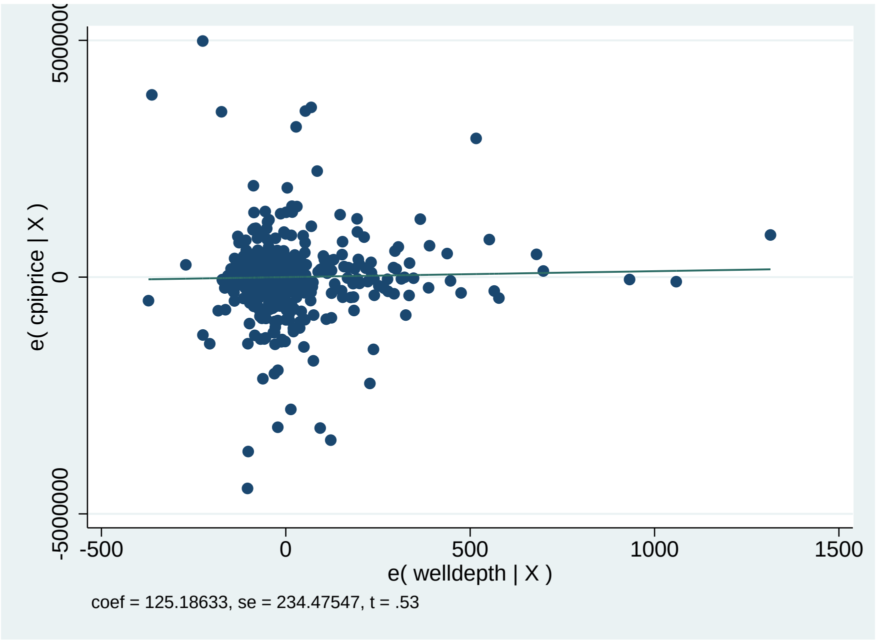

Figure 6.5: *Well Depth* Added Variable Plot

Appendix A.6: Dependent Variable Distribution

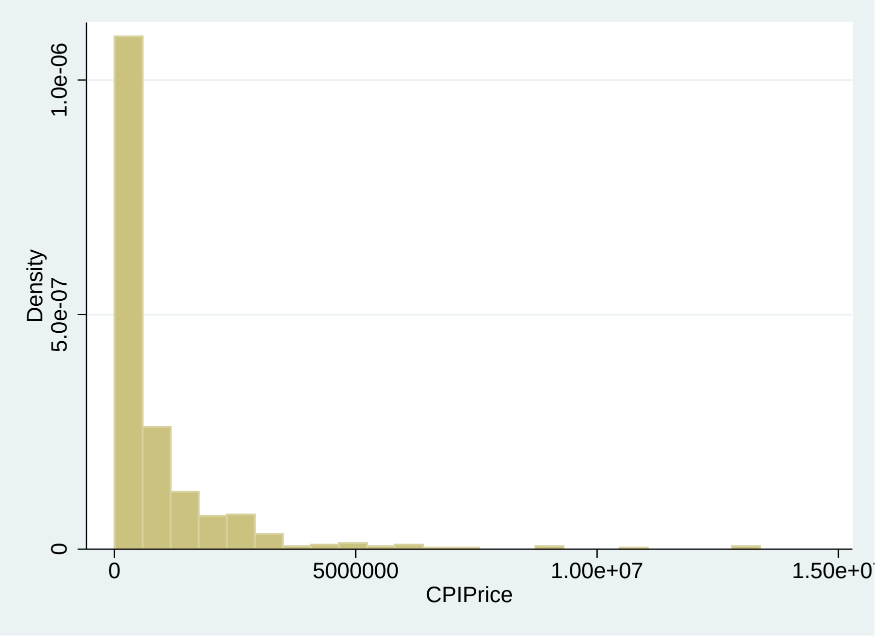

Figure 6.6: Distribution of *Sale Price*

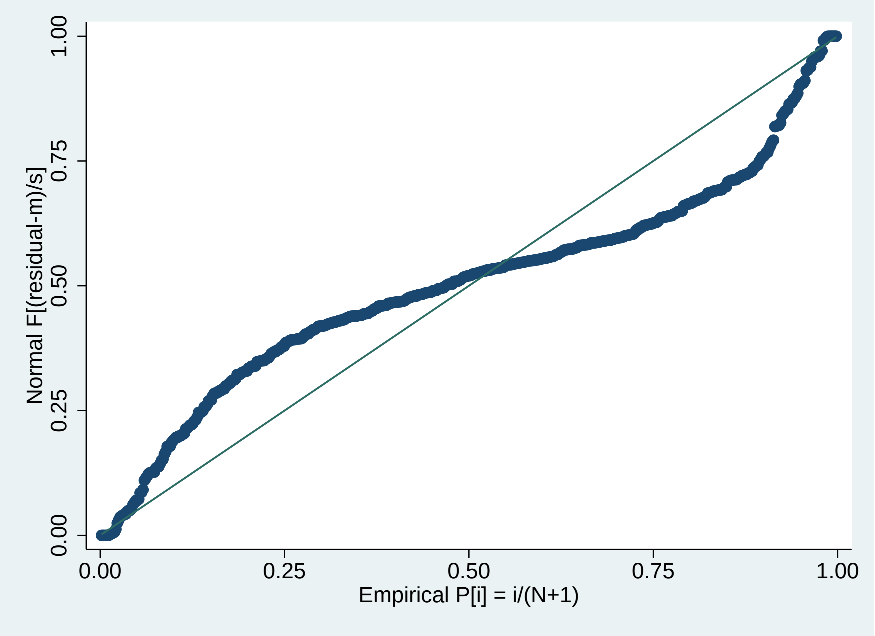

Figure 6.7: Standardized Normal Probability Plot (Linear)

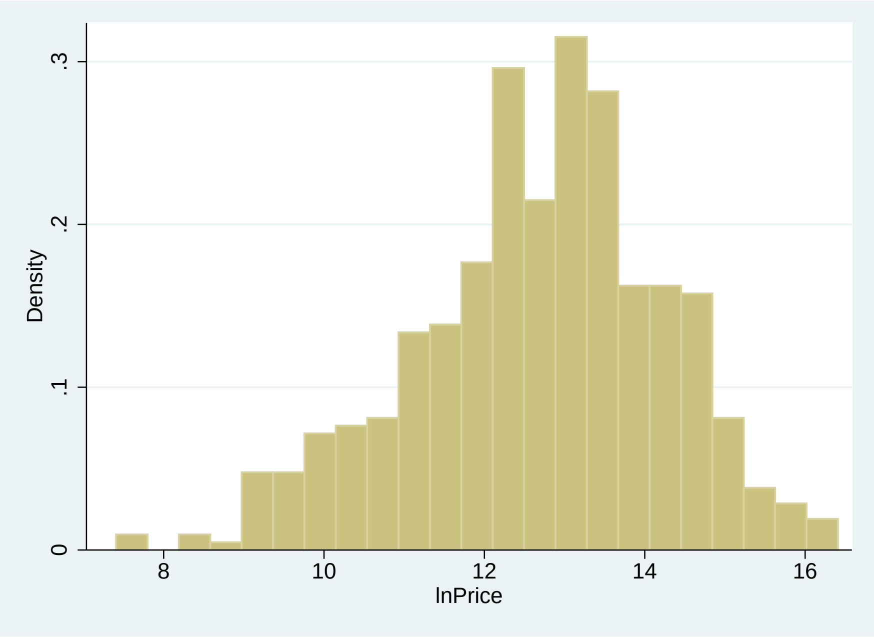

Figure 6.8: Distribution of *Sale Price* When Logged

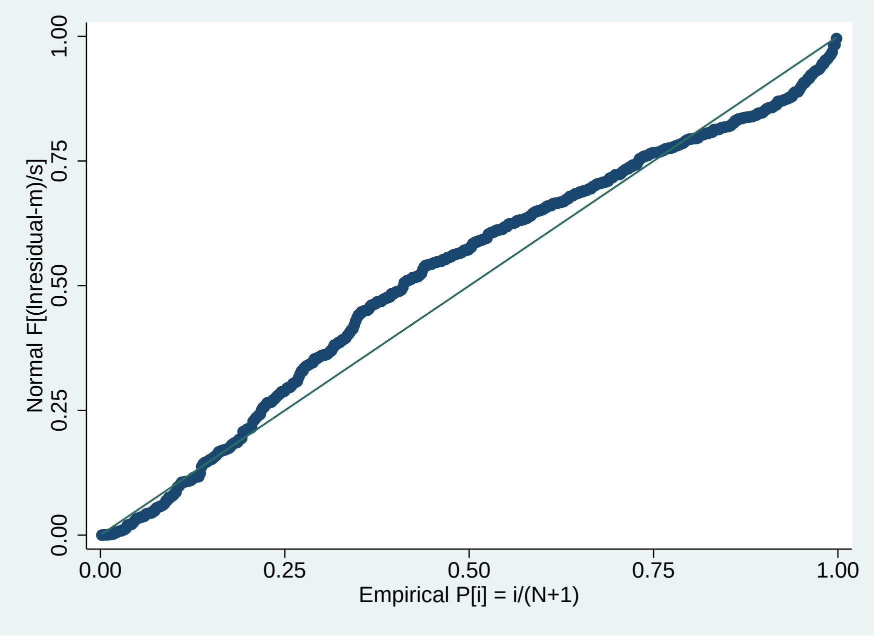

Figure 6.9: Standardized Normal Probability Plot (Logged)

Appendix A.7: Final Model: Log-Linear Regression Full Results

Table 6.6: Final Model: Log-Linear Regression

Variable	**Coefficient**	**T-Statistic**	**Std. Error**
Logged Sale Price			
Year			
Year=2015	-0.144	(-0.90)	0.161
Year=2016	0.326*	(2.00)	0.163
Year=2017	0.425*	(2.13)	0.199
Month			
Month=2	-0.251	(-0.99)	0.253
Month=3	-0.341	(-1.48)	0.230
Month=4	-0.368	(-1.49)	0.247
Month=5	-0.139	(-0.57)	0.244
Month=6	-0.518*	(-2.51)	0.241
Month=7	-0.228	(-0.89)	0.257
Month=8	-0.519	(-1.89)	0.275
Month=9	0.219	(0.83)	0.264
Month=10	0.124	(0.48)	0.257
Month=11	-0.115	(-0.46)	0.250
Month=12	-0.039	(-0.17)	0.229
County			
County=Franklin	-0.159	(-1.09)	0.147
County=Adams	-0.331*	(-2.04)	0.162
Productive Component			
Improvement Value	-0.000000149	(-1.05)	-0.000000142
Permanent Crop Value	0.000000605*	(2.23)	0.000000271
Irrigated	0.00492***	(6.63)	0.00074
Dryland	0.000846***	(6.48)	0.00013
Homesite	0.0343*	(2.50)	0.0137
NonCrop	0.000466**	(2.99)	0.00016
Other	-0.0168	(-1.54)	0.0109
Pasture	0.000754	(1.93)	0.00039
Water Component			
In CBP	0.512**	(1.69)	0.180
In Odessa	0.307	(2.83)	0.180
Well Depth	0.00084**	(2.75)	0.0003
Consumptive component			
Commercial Zone	1.702**	(2.63)	0.647
Suburban Zone	-0.395**	(-2.81)	0.140
Other Zone	-0.436	(-1.69)	0.258
Spatial Component			
Canal Distance	0.0283***	(4.04)	0.007
Town Distance	-0.0114	(-1.45)	0.149
Interactions			
Irr*WellDepth	-0.00000276**	(-2.66)	0.00000104
Irr*InCBP	0.00477***	(4.65)	0.0010
Constant	11.59***	(36.24)	0.319
Observations	516		
R^2	0.546		

t- statistics in parentheses
*p $<$ 0.05, **p $<$ 0.01, ***p $<$ 0.001